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DEVELOPMENT OF A CRASHWORTHY, ARMORED, UNIVERSAL CREW SEAT FOR U. S. ARMY AIRCRAFT

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U. S. ARMY TRANSPORTATION RESEARCH COMMAND

FORT EUSTIS, VIRGINIA

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KAMAN AIRCRAFT CORPORATION

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Investigation of aircraft accidents and results of dynamic crash tests of representative types of Army aircraft have pointed up the design strength inadequacy of crew seats manufactured in accordance with existing military specifications. Also, experience has proved the need for personnel armor protective systems for aircraft crews operating in combat areas. To determine the feasibility of integrating armor protection into the basic design of a crew seat fabricated to meet specific crashworthiness criteria, the U. S. Army Transportation Research Command negotiated contracts with four different airframe manufacturers.

This report, prepared by Kaman Aircraft Corporation under the terms of Contract DA 44-177-AMC-93(T), represents the approach of one manufacturer toward a solution to the problem. In addition to crashworthiness criteria and armor protection, the work under this contract included investigation of the possibility of designing a crew seat having universal application to many types and models of Army aircraft. This Command reserves comment on the appropriateness of the Contractor's conclusions and recommendations, pending the results of programmed flight, ballistic, and dynamic crash tests of the seats reported on herein.

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SUMMARY

This program developed five experimental armored crashworthy crew seats for application in Army aircraft.

Study and analysis indicated that a universal crew seat or family of seats may be adapted for usage in existing Army aircraft. Structural reinforcement would be required to withstand the higher seat loads and compromises would be necessary to clear equipment and to adapt to varying structural configuration.

Problems of optimum restraint, crash load attenuation, armor selection, armor coverage, mechanical system and structural system are discussed.

To achieve the safety objectives of the seat system, improvements to the standard restraint harness have been recommended.

Installation of the armor introduces clearance problems especially with aft control stick travel. Resolution of this problem may require aircraft variations.

Supply and maintenance of future aircraft would be enhanced by the application of an armored crashworthy crew seat. Specifications, which control the seat installation and the area around the seat, are necessary to achieve universality in these aircraft.

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INTRODUCTION

Recent operations in Asia have proven the need for aircrew protection from small arms fire. Also, in recent years it has been realized that aircrew seats crashworthiness criteria were inadequate. Research in crash safety has repeatedly shown that survivable crash loads were much more severe than seat design criteria.

Achievement of acceptable armor protection confronts the designer with severe problems of comfort, cockpit space limitations, and weight. Crashworthiness involves both the latter two problems and the additional problems of energy absorption to limit the acceleration levels experienced by the seat occupant. All of these problems are aggravated in smaller classes of aircraft.

This program contemplates the creation of a basic seat design, incorporating both armor protection and crashworthiness, capable of installation in all size classes of Army aircraft. Contract objectives included a definition of this basic seat and a study of the degree of compromise required to adapt the seat to the various aircraft classes. A major objective of the overall program (including the test phases not performed by the contractor) is felt to be a determination of seat weight and space requirements which would be of use in formulating design specifications for future Army aircraft.

The following aircraft were studied for application of a common seat or family of seats:

1.	O-1E	3.	U-1A	5.	CH-47	7. UH-1B
2.	U-6A	4.	CV-2A	6.	CH-34	

As will be shown, a seat design was evolved, which, with appropriate support modifications, could be installed in these aircraft. In all cases, some degree of compromise would be involved in the installation.

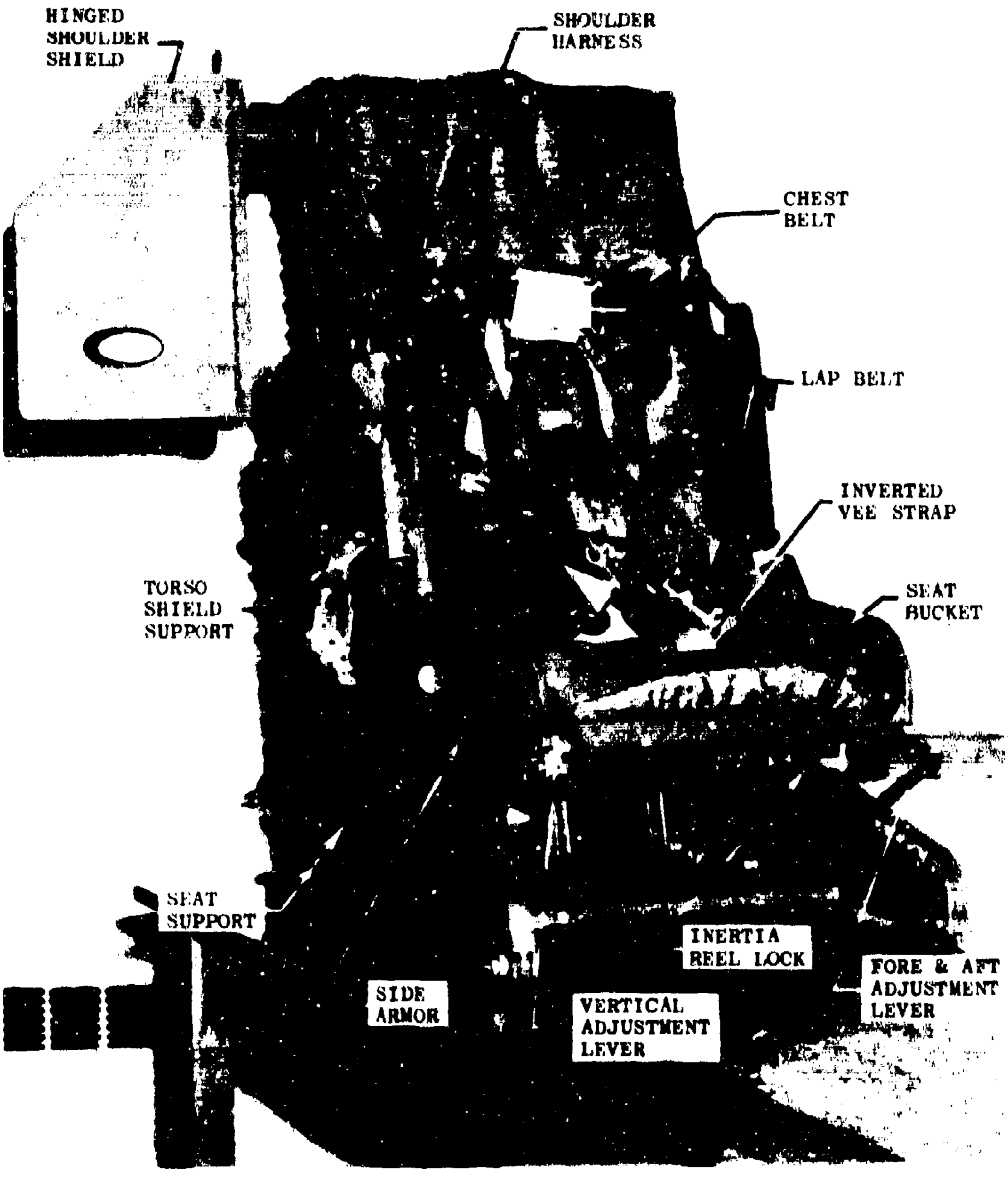


Figure 1. Seat Assembly (Torso Shield Not Shown)

CONCLUSIONS

1. A crashworthy armored seat essentially fulfilling the objectives of the Work Statement is practical and could be accommodated (dimensionally) by all size classes of Army aircraft. Compromises which allow for variations in space and structural provisions are necessary to permit installation of the seat in existing aircraft.

2. Because the supporting structure is not designed to the strength requirements of the seat, the seat would probably not develop its full crashworthy potential in existing aircraft without extensive structural modifications to the aircraft. This would probably be particularly true of the smaller existing aircraft.

3. Such a seat could realize its crashworthy potential more fully and efficiently in a new aircraft, in which original design specifications could provide for the seat by specifying:

   (a) Adequate strength in seat backup structure, and

   (b) Adequate clear space under the seat for energy absorbing stroke.

4. Allowing 20 pounds for the mean weight of currently used crew seats, the weight penalty (in the seat itself) should not exceed:

   40 pounds for crashworthy features
   150 pounds for crashworthy features and armor

   The weight penalty in the airframe resulting from 3 (a) and (b), above, would be in addition.

5. Compromises in control clearance would be involved in all existing aircraft studied if armor protection for the torso in the forward sector is required.

6. Compromises in energy absorption stroke would be involved in all existing aircraft studied, if the crashworthiness feature is required.

7. Present shoulder harness geometry is inadequate for the protection of crewmen at the deceleration levels contemplated by the Work Statement.

RECOMMENDATIONS

1. For any Army aircraft:

   (a) Consider testing crashworthy-design seats under conditions wherein vertical accelerations are combined with simultaneous fore and aft accelerations to determine the effects on energy-absorbing devices.

   (b) Consider testing to determine the effects in inducing spinal compression, of forward loads on shoulder harness geometry.

   (c) Consider the development of an integrated restraint system, including adequate pelvic support and possible head restraint.

2. For existing Army aircraft:

   If the crashworthiness feature is required, consider the seat and its backup structure as a single system and determine the strength and deceleration characteristics of this system in the presence of combined vertical and forward loadings.

3. For future Army aircraft:

   (a) Consider modification to MS 33575 cockpit dimensions to resolve interferences between the control throw and the chest armor.

   (b) Consider specifications for seat backup structure strength requirements and seat space requirements to assure that the aircraft is compatible with the crashworthy armored seat.

DISCUSSION

GENERAL

The seats were designed with the following objectives, which are the specifics of the Work Statement:

1. Provide fore and aft and up and down adjustment of the seat.

2. Provide protection against 7.62 mm AP projectiles fired at a range of 100 yards and striking at 15 degree obliquity.

3. Protect the trunk-torso body area of the air crewmen, when seated in the normal manner, against fire delivered from positions below an imaginary horizontal plane passing across the shoulders of the pilot/copilot, while the aircraft is in level flight attitude.

4. Provide protection against multiple hits striking more than 6 inches apart.

5. Protective equipment will not restrict or interfere with the movements of the crew required in normal operation of the aircraft.

6. Protective equipment will not interfere with the normal operation of the aircraft.

7. Protective equipment will not unduly restrict the external field of vision of the crew, nor impair depth or color perception nor degrade visual acuity.

8. Protection equipment will include quick release or disconnect features, as necessary, to permit rapid egress from the aircraft in emergency situations.

9. Protective materials will be fire retardant.

10. The seat, its support system (exclusive of airframe structure, and the occupant restraint system, individually and in combination, shall have sufficient strength to withstand the reaction from longitudinal

decelerations of 25g for 0.20 second and 45g for 0.10 second combined with lateral decelerations of 10.5g in the pelvic region of a suitable anthropomorphic dummy having a weight and mass distribution of that of the 95th percentile man. Progressive plastic deformation of the seat is permissible provided complete failure and subsequent injurious situations do not occur.

11. The seat, its support system (exclusive of airframe structure), and the occupant restraint system in combination, during high vertical impact conditions, shall be capable of continuously maintaining 20g +3g, in the pelvic region of the dummy described above, while deforming through 12 inches of vertical travel with respect to the airframe and, where possible, up to 15 inches or more of vertical travel.

12. The seat system must restrain the occupant, during or after impact, in such a manner as to maintain alignment of the occupant's torso in a normal sitting position.

13. The system will present no projections or cutting edges in the event of failure due to loads in excess of the design values.

14. The restraint system will include a lap belt, shoulder harness, and crotch or thigh strap(s).

First studies of seat installations in the subject aircraft showed that a completely interchangeable seat installation could not be simply achieved in the existing aircraft due to the diversity of structural attaching points.

For example the following is a tabulation of the width between seat attaching points for the aircraft:

Aircraft	Width Between Structural Attachments
O-1E	14.50
CH-47	20.14
H-34	18.00 (Bulkhead Mounted)
U-6	12.00
CV-2A	20.30
UH-1	16.00

In addition to the width differences noted above there is the same diversity in fore and aft location of frames and attaching points in relation to the seat position for each aircraft.

A feasible approach to the universal seat is to design a seat which, with minor structural variations, can be installed on the floor of aircraft like the CH-47 and CV-2A. Such a seat could be adapted to the narrower support spacing of the remaining aircraft through the use of a structural box. This adapter box, in effect, would create a false floor for mounting of the standardized seat. This elevated false floor would reduce the load-limiting stroke during crash, but, with proper design, buckling of the adapter box would contribute to the required energy absorption.

This approach, however, assumed structural strength in the existing airframe backup structure adequate to carry, without substantial deflection, enough load to operate the energy absorber. If the aircraft structure is appreciably weaker than the seat, deformation of the structure can allow the seat to pull loose, cock, or otherwise assume a random attitude prior to structural "bottoming out", in which case proper operation of the energy absorption means cannot be assured.

Since the Work Statement excludes consideration of the aircraft structure, it cannot be stated that seats furnished would be permitted to devolop the full measure of crashworthiness designed into them. As a consequence, and as a result of discussions with USATRECOM representatives, the experimental seats are designed to be floor-mounted and to have an energy absorption stroke which travels the seat to the floor.

The contractor has furnished, at USATRECOM's request, simple plate adapters connecting the seat mounting points to the existing structural hard points of the test aircraft, to permit installation without modification of the aircraft. These adapters are considered test hardware and are designed to carry maneuvering loads only. Sufficient margin is provided to carry moderate crash loads. The weight of these adapters should be excluded from any consideration of seat weight.

In addition to structural variations, there is the problem of space requirements. All of the subject aircraft have intrusions into the area that would be occupied by the seat system.

A general problem is that of clearance with the pilot's controls. In all the subject aircraft, normal stick or wheel aft travel touches or barely misses the pilot's torso. Interposing an armored protective torso shield results in control interference except in the most aft seat positions. This interference negates the fore and aft seat adjustment function and emphasizes the problem of accommodating the shorter pilot. This problem has not been solved because the large pilot with parachute harness and restraint system requires that the torso shield be well forward, while control travel requires that it be well aft.

These opposing requirements cannot be satisfied by seat design alone because the short pilot, who needs the forward seat position, does not necessarily have a small chest. (See page 86 in Reference 18.) The noted table shows that chest depth and stature are widely variable and that the 65-inch stature may have the same 10-inch chest depth as the 74-inch stature. Because of the diverse requirements, control interference with the torso shield cannot be eliminated for all seat positions. For the experimental seat flight testing, the seats must be positioned to clear the controls when the torso shield is in use.

In future aircraft which may require pilot torso protection, allowance should be made to permit torso shield installation without interfering with operation of the pilot's controls.

A special requirement for the helicopter seat is space allowance for operating the collective stick. Full travel of the stick sweeps the left arm through a large area on the left side of the seat.

Clearance for the pilot's hand on the collective stick is a factor which limits allowable seat width. Arm clearance is a factor in determining shoulder armor location and seat support configuration.

Because of the noted variations in the seat installation requirements for the subject aircraft, universality can be achieved only in the seat bucket. Each support must be adapted and fitted to the individual aircraft.

The seat bucket of the experimental seats conforms generally to MIL-S-5822 and with an average of the seats in the existing aircraft. A 3-inch thick foam seat cushion is provided. While it is recognized that optimum crashworthiness is attained by seating the pilot directly on seat structure eliminating any soft elastic element in the system, it was felt that this would result in a seat which would be impractical because it would be excessively uncomfortable to pilots. It is true that space can be developed, in a crash, between the pilot and his restraining harness as a result of cushion deflection. This is also true of a rigid/crushable type of seat pad. However, considering initial deflection of the cushion when the pilot seats himself, and "solid heighth" of a fully compressed foam pad, this space will be much less than the full 3-inch thickness of the uncompressed cushion. Potentially injurious rebound energy stored in the compressed airframe structure will be limited to 25g headward by the seat's energy absorber, which operates in both directions. The degree to which potentially injurious rebound energy might be stored in the sprung mass of the seat bucket itself, and, therefore, the significance of elastic cushion from a crashworthiness standpoint, should be readily determinable from dynamic test results.

The parachute thickness allowance is 4 inches.

The back of the seat is made of three flat panels which conform approximately to the parachute pack shape.

The seat support of the experimental seats is configured for minimum protrusion into the area occupied by the crewmen. The concave shape (see Figure 1) of the support clears the pilot's arms during the energy absorption stroke in a crash, and makes for easier postcrash egress. This design approach results in a somewhat heavier support structure; however, the added safety and ease of operation are considered a reasonable trade-off for the estimated 5 pounds per seat weight increment.

INSTALLATION CONSIDERATIONS IN ARMY AIRCRAFT

Seat installations in the subject aircraft will have a variety of problems which must be met with compromises to allow seat installation. For example:

1. In the O-1E aircraft, the aft rudder pedals extend into the area under the forward seat. Serious design variations and compromises would be necessary to make the rudder pedal installation compatible with the seat space requirements. The shoulder shields of the experimental seats interfere with free access to the window and door handles, and it is probable that an optimum installation would integrate the shoulder protection into the aircraft structure instead of the seat.

   An adapter is required to fit the standardized seat to the O-1E aircraft structure. This adapter would have the special problem of clearing the control system torque tube which is above the aircraft floor. Energy-absorption stroke would be shortened by the height of the adapter assembly.

2. In the UH-1B, the adapter to fit the seat to the structure would have special problems of clearance with the collective stick installation, access to floor openings for maintenance, and clearance for the heater outlets. The shoulder protector again impedes access to the door handle, and supporting this armor from the structure may be necessary for optimum design. A special factor in the UH-1B is the low position of the collective stick, which requires that the pilot lower his left shoulder to get full down collective. Space allowed to permit this motion reduces the armor coverage in the left underarm area.

3. In the CH-47, aft and upward travel of the seat is limited by the canted bulkhead behind the pilot. This clearance requirement results in reduced energy-absorber travel because the seat must be aft to clear the control stick and must be in a low position to clear the canted bulkhead. The seat installation in the CH-47 is enhanced by the special collective stick, which occupies minimum space above the floor, and by the existing backup beams, which are spaced wide enough to nearly coincide with the requirements of the seat support.

4. The CV-2A seems best suited for installation of the crashworthy armored seat. The structural backup for the existing seat is spaced to be suitable for the seat support. Space is adequate for seat installation. Allowances must be made for the trim control installation and for adjacent equipment and controls, but these problems appear to be minor and routine.

5. The H-34 has the unique requirement for bulkhead mounting, and the existing seats have the capability of hinging to permit access to the cockpit from below. This seat installation will be considerably different from the floor-mounted seat, but many components such as armor panels, energy absorber, and some structural members may be common parts.

6. The seat installation in the U-1A is difficult because of interferences with trim controls, flap hydraulic pump and system, and other equipment under or adjacent to the seat. The armored seat bucket itself may be installed with minimum changes, but the energy-absorbing system would require significatn reduction in stroke or complete deletion unless significant airframe changes were contemplated. The most desirable trade-off of seat/airframe compromise involves considerations of military requirements and economics beyond the scope of this contract.

7. The U-6A seat installation has close side and aft clearance requirements. Heater system components and an emergency hydraulic system under the pilot's seat protrude into the seat area. As in the U-1A, installation of the armored seat bucket on a support which meets the space requirements will result in reduced energy-absorption capability.

ENERGY ABSORPTION

To prevent spinal injury, compression loads on the spine must be limited to those generated by 25g vertical loads. Since the anticipated crash loads are much in excess of this safe limit, it is necessary to provide load-limiting energy absorbers which isolate the seat from the critical vertical loads. To be effective, the energy-absorbing stroke must be as long as practical.

Various mechanical energy absorbers were considered. These include:

1. Crushable materials such as aluminum honeycomb, other aluminum foil shapes, balsa, and plastic foam.

2. Metal deforming devices such as metal drawing or extruding, metal bending.

3. Frangible tubular strut shattering as it is compressed onto a die which flares the tube end beyond its elastic limit. See Reference 6.

4. Friction slides which depend upon holding effect of a sliding brake.

5. Hydraulic struts which maintain load by metering or hydraulic fluid through an orifice.

The following factors are considered essential in the selection of the energy absorber:

1. The device must be bidirectional. Load reversals can and do occur during crashes (as shown on page 36 of Reference 17), and unidirectional energy absorbers (such as crushable material beneath a seat only) will not adequately protect the occupant. If a unidirectional device is employed, it requires at least an antirebound device. as shown in Reference 15.

2. The energy absorber must fit into a small volume in order to achieve minimum size for the seat support which is vital for universal application.

3. The energy absorber must be simple and predictable for reliable operation. In the vast majority of cases it will never be called upon to act. In the rare case where a crash does occur, the device must operate reliably after perhaps years with no attention. This requires simplicity and complete freedom from required adjustments.

The metal-bending type of energy absorber was selected for use in this program. The unit absorbs energy by bending and rebending four metal straps around a set of pins. (See Figure 2.)

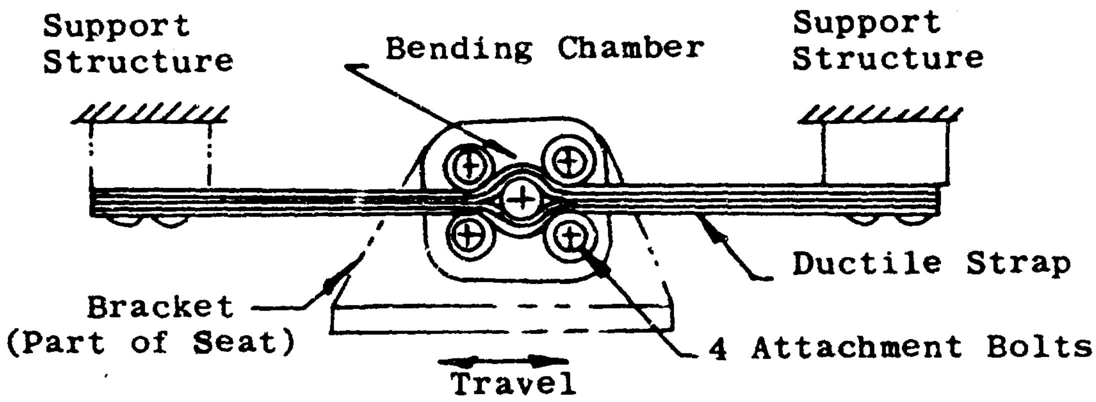


Figure 2. Energy Absorber

This unit was selected for the following reasons:

1. It is an operationally proven device.

2. It is bidirectional. Antirebound mechanism is inherent.

3. It is a small package (1.56 x 1.25 x 16.75 inches) which may be compactly incorporated into the seat assembly.

4. Stroke is limited only by the length of the strap.

5. This type of energy absorber is suited for bulkhead-mounted seats as well as floor-mounted seats.

6. Energy absorption capability may be readily varied by change in strap width. If a criterion-type change should be made after a production quantity of seats is in the field, retrofit of new straps would be simple and inexpensive.

To conserve space and to simplify the mounting of the seat bucket, the load limiter was installed in a position parallel to the seat back. Hence, load limiting travel is parallel to the seat back. It was considered that this travel would provide maximum alleviation of load on the occupant's spine and would be most suitable for a universal seat.

SEAT TRAVEL

The Work Statement objective of 12 to 15 inches of vertical travel for energy absorption requires that this much space be available beneath the seat in its lowest adjustment. Existing aircraft do not approach this desirable objective. Since the seats for installation in existing aircraft must place the pilot in the same position with respect to controls and instruments as the aircraft's normal seat, the stroke available to the energy absorber is necessarily limited to less than the desirable 12 to 15 inches.

Obviously space for increased stroke could become a specification requirement of new aircraft. The design presented herein is limited in stroke only by the space limitations of the aircraft in which it is installed. Changes in seat support height and energy-absorber length will permit the longer recommended energy-absorber stroke.

The adjustable height of the seat reference point above the heel rest line is 10.00 to 14.50 inches. Energy-absorption travel is the seat height less 5 inches. That is, the seat will travel 9.5 inches from its high position and 5 inches from its low position to bottom out on the seat track and seat support structure.

The seat height agrees with the UH-1B and O-1E. The top height is approximately 1.5 inches lower than that of the CH-47, but interference with the aircraft bulkhead behind the pilot precludes this high position.

To meet the stroke requirement of the energy-absorption system, the seat and bucket must travel until the system nearly reaches the cockpit floor. Any obstruction which shortens this travel will reduce the effectiveness and safety of the energy-absorbing system.

The O-1E, U-6A, and U-1A aircraft all have equipment, controls, structure, or plumbing which interferes with travel of the seat bucket to the floor during the energy-absorption stroke. For future aircraft, the requirements of the crashworthy seat should govern in this area.

ARMOR CONSIDERATIONS

MATERIAL

A hard-faced composite, made from ceramic tile with laminated backing, was selected as the armor material. The contractor was guided in this choice largely by Reference 10. Independent consultation with competent suppliers of both armor materials and armament reinforced this decision. No alternate materials or types of construction were found which could compete with the chosen material on a weight basis.

In order to achieve minimum weight and minimum envelope for the seats, a design approach was taken which used the armor panels as structural elements of the seat. The back and seat armor panels are essential parts of the seat bucket structure. A part of the weight saved by permitting the armor backing material also to carry structural loads is reinvested in additional armor coverage and in features (discussed elsewhere in this report) to increase the crashworthiness of the seat.

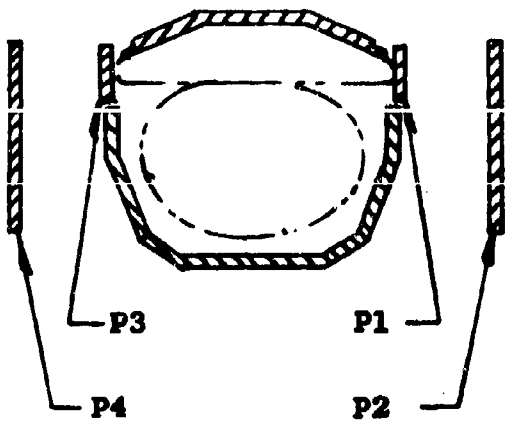
The side armor panel, the shoulder panel, and the torso shield are easily removed for replacement. Because the seat and back armor panels are integrated into the seat structure, some weight sacrifice was made to provide for ease of seat bucket replacement to minimize down time due to armor damage. Individual bucket panels would also be interchangeable, on a production quantity of seats made from hard tooling.

ARMOR COVERAGE

The ideal situation (from gunfire protection) of having the seat occupant completely enveloped in armor must be compromised in favor of:

1. Weight
2. Adequate clearance for pilot's vision
3. Adequate clearance for pilot's operation of controls
4. Adequate clearance for ingress and egress from aircraft.

The armor configuration which was developed to protect the occupant and to permit normal and emergency operation is shown in Figures 3 and 4.



SECTION A-A
(ROTATED)

The configuration shown is for tandem seating. For side-by-side seating, inboard panels P1 and P2 are omitted from the right-hand seat and inboard panels P3 and P4 are omitted from left-hand seat.

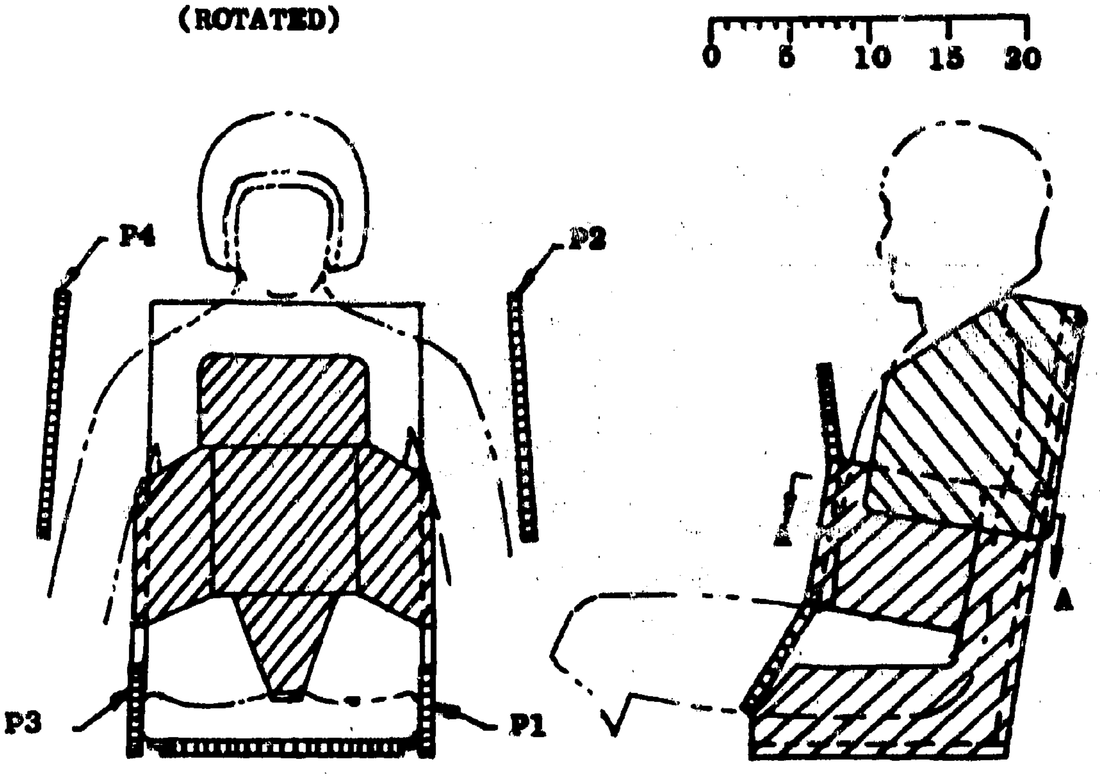


Figure 3. Armor Coverage

Figure 4. Seat with Occupant Demonstrating Torso Shield Travel.

The armor coverage provided by the seat is apparent from Figures 3 and 4. The back, bottom, and sides of the seat bucket are protected, except for narrow strips at the edges. These areas could readily be included in the protected areas on a production quantity of seats sufficient to justify the necessary tooling. In addition, a hinged shoulder shield is provided to protect the upper arm and upper torso from fire from the side. Hinging is necessary for ingress and egress. In aircraft with side-by-side pilots, one such hinged shoulder shield is used on the outboard side of each seat, the assumption being made that the inboard sides are protected by the opposite seat. In tandem aircraft, two shoulder shields may be used, one on each side.

Protection from fire from the forward sector is provided by a detachable torso shield, which protects the upper torso and groin, as shown in Figure 4.

This coverage was worked out empirically, in concert with the contractor's Flight Test Staff, with the aid of mockups.

TORSO SHIELD

This portion of the armor represented the greatest design problem and is felt worthy of separate discussion. Despite the difficulties which are apparent with a torso shield (such as aft control throw interference and restriction of pilot's motion), it was felt to be the only feasible method of providing significant forward protection integrated with a seat.

The following features of the torso shield were considered to be design requirements:

1. Depth to clear 95th percentile pilot's chest.
2. Underarm height nonrestrictive to 35th percentile pilot.
3. Easily detachable for ingress and egress.
4. Fully supported from seat.
5. Connected to seat until released. Crash loads cannot be permitted to dislodge torso shield and make a missile of it.
6. Single point of release.

7. Provision for pilot to reach instrument panel or overhead panel (lean forward) without disconnecting the structural support.

8. Protection of pilot by upper front portion without interference, and yet without guillotining the pilot or crushing his face if forward crash loads snap head forward upon shield.

The torso shield provided meets these requirements. Its barrel shape is formed from multiple connected flat panels for the experimental seats; for a production quantity justifying the tooling, the shield could be furnished in one-piece construction with no fasteners except in the upper front. The latter is connected with breakaway shear pins for the reasons stated in feature 8 above.

The torso shield is strapped to a four-bar linkage train which supports the shield and allows it to travel in front of the pilot (see Figure 4). The travel permits the pilot to lean forward and reach switches or controls on the instrument panel or the forward overhead panels.

The four-bar linkage is used to support the torso shield for the following reasons:

1. Protrusion into pilot's operating area is minimized.

2. Direct structural connection to seat structure is achieved.

3. Necessary freedom of motion is provided.

4. Restraint system is not compromised by requirements of torso shield support.

5. Weight of torso shield is supported at all times by the linkage.

6. Single point of release is provided.

7. Torso shield does not add to crash loads applied to seat occupant.

Latches are provided to connect the shield to the seat structure. The latched condition is the normal mode for almost all flight situations. Release of the latch is effected by raising the shield approximately 1/2 inch and leaning forward to separate the latch and allow

motion. Re-latching of the shield is accomplished by pushing the shield back to the seat. Slight upward pressure is necessary to reach the position where both latches will drop into the retaining hooks of the seat structure.

The torso shield is attached to the support linkage by a nylon strap which encircles the shield and bolts to the linkage. The strap has a buckle for adjustment, positive tensioning and quick release. Installation of the torso shield consists of placing the shield into the guide channels of the support linkage and buckling the strap. Removal of the shield is accomplished by operating the buckle of the retaining strap and moving the shield forward out of the guide channels.

The high load capability of the seat system demands that the restraint system be of optimum configuration. An optimum restraint system should support and safely restrain the crewman during crash, allow freedom to operate the aircraft, be simple to operate, and be universally suited for all sizes of crewmen.

To be safe, the restraint harness should not induce critical loads into the crewman's body or allow the body to be loaded in a manner which may cause injury.

The standard shoulder harness is less than optimum because forward loads induce compression loads in the crewman's spine.

When forward and downward loads are considered as acting simultaneously, the spineward compression induced by the standard shoulder harness is additive to the aircraft downward load. If a combined loading of 45g forward and 20g downward (aircraft load factors) is assumed, the resulting loads developed in the crewman are critically high. The analysis upon which this is based is given in Appendix I.

While the analysis is uncertain because of belt friction factors, body dynamics and internal load distribution, the magnitude of the calculated induced load (28g) is too high to be disregarded. A load only one-third as high when added to the direct spinal compression due to vertical loads will be critical. Any load increment added to spinal compression tends to negate the function of the load relief system. For this reason upper torso support, which acts directly to restrain without inducing spinal loads, is necessary for a safe restraint system.

From page 13 in Reference 2, about 70 percent of injuries which were attributed to pure decelerative forces involved the spinal column. In rotary-wing aircraft, most of these spinal injuries (70 percent) occurred in accidents with high vertical forces. In fixed-wing, less than half (45 percent) the spinal injuries occurred in accidents with high vertical forces.

Incidence of spinal injury without causative high vertical forces seems to support the position that the restraint harness may be inducing critical loads into the survivor.

Pelvic support is another critical factor in the restraint system.

During crash, high inertia forces of the leg act to pull the pelvis into a tilted position ("submarining").

Any tilting of the pelvis causes eccentric loading and bending of the lower spine and vertebrae; failure may result. Such an injury may result in fatal damage of the spinal cord or incapacitation, which may cause the survivor to succumb to postcrash factors, such as fire.

One experimental seat includes an inverted vee strap for pelvic support and a chest safety belt for upper torso support.

It was considered beyond the scope of this program to carry out the necessary development, testing, and evaluation which would be required to develop the optimum restraint system. The experimental restraint system is a first step toward a suitable restraint harness.

A program which examines all factors and establishes, by test and subjective evaluation, the detail requirements of the system is necessary for achieving the optimum restraint system.

MECHANICAL CONSIDERATIONS

The designer is tempted to save weight by providing for vertical energy-absorption travel (and adjustment travel) via slides. However, systems which may operate admirably on slides during a test in which only vertical accelerations are applied could very easily malfunction (with disastrous consequences to the seat occupant) during an actual crash, in which the vertical acceleration is accompanied by simultaneous forward and/or lateral accelerations. Since the seats will be flown, as well as tested, the contractor has elected to make a further weight sacrifice to assure that vertical load limiting is not unduly influenced by fore and aft or side loads.

From page 44 of Appendix I, seat bucket guide loadings were derived. The maximum combined seat guide loading occurs in the condition Px + Py + Pz:

$$
\begin{aligned}
E_x &= 8191 \\
F_x &= 12869 \\
F_y &= 6620 \\
G_x &= 940 \\
H_x &= 5027 \\
H_y &= 3265 \\
\hline
\text{Total} &= 36912 \text{ pounds}
\end{aligned}
$$

Note: "J" is not a seat guide load.

For energy-absorption travel, the minimum combined seat guide loading occurs during the condition Pz = 6000 pounds:

$$
\begin{aligned}
E_x &= 2650 \\
F_x &= 5300 \\
G_x &= 2650 \\
H_x &= 5300 \\
\hline
\text{Total} &= 15900 \text{ pounds}
\end{aligned}
$$

Note: Omit F_y and H_y because they result from a nonsymmetrical loading which may not occur.

A rolling guide system and a sliding guide system were investigated. The slide system which had the advantages of simplicity and low cost was checked first. Because of the high variable loads on the guides, it was imperative that the coefficient of friction be small and predictable. The coefficient of sliding griction is sensitive to contamination, humidity, surface finish, velocity of sliding, and bearing pressure. Since all of these factors would be impossible to control, it was concluded that only a low

friction roller system would allow the load limiter to operate within the 15g-25g specified limits. The effects of guide roller friction are discussed in detail on page 33 of Appendix I.

The seat bucket adjusts vertically on tracks of the seat support, and the support adjusts fore and aft on floor tracks. "Vertical" adjustment is actually parallel to the seat back in order to conserve cockpit space. The seat is spring balanced by four 35-pound extension springs which maintain an upward force on the seat bucket when the seat is being adjusted.

The vertical adjustment is held by shear lugs on the bucket which latch into a notched guide on the seat support. This notched guide is linked to the seat support by the load limiter so that the seat may travel its energy-absorbing stroke from any adjustment position. The fore and aft position is held by shear pins which protrude from the support assembly into the forward track.

The vertical adjustment lever is inside the seat bucket on the right side. The handle protrudes forward of the seat in position for easy operation. Upward motion of the handle retracts the shear lugs which hold the seat in position. The fore and aft adjustment lever is at the left side of the seat support, and upward rotation of the lever retracts the shear pins and allows fore and aft seat motion.

The inertia reel is attached to the upper back of the seat. The reel lock is under the left side of the seat bucket within easy reach of the pilot but concealed so that it does not interfere with the energy-absorbing stroke.

STRESS ANALYSIS

In the structural analysis of the seat design, it is considered that the area of prime importance is the translation of the specified load factors into loads and the distribution of these loads upon the several components of the seat. This, therefore, is treated in considerable detail in Appendix I.

The detailed sizing of individual seat components, number and size of bolts, etc., is considered routine engineering, and is not repeated herein in detail; several typical examples are shown (in Appendix II) of the detailed stress analysis of critical areas of the seat. Methods are typical of standard aircraft stress analysis procedures which have been applied throughout.

As previously stated, the armor panels are integral structural elements of the seat. Applied loads to be carried by the armor were determined by the contractor, as shown in Appendix I. The detailed stress analysis of the armor panels was conducted by the supplier of the armor. Typical examples of this analysis are included in Appendix II.

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APPENDIX I

LOAD ANALYSIS

The seat assembly consists of two major components. They are the seat bucket and the support structure. The seat bucket is suspended within the support assembly.

The occupant loads the seat by direct contact and by the restraint harness. The seat loads the support by roller and track systems for longitudinal and lateral loads. Vertical loads are carried from the seat back panel to the vertical adjustment mechanism which is suspended on the load limiter strap. This load limiter is bolted to the center of the aft web of the support assembly.

The support assembly is tied to the floor at its four corners. The aft fittings carry vertical and side loads. The forward fittings carry vertical and longitudinal loads.

This section deals with distribution of loads at the major points of transfer; namely, the harness attachment points, the seat support rollers, the load limiter, and the floor attachment fittings.

SEAT LOADS

The seat ultimate loads are as follows:

1. Longitudinal - 45g for duration of .10 second, 25g for duration of .2 second.

2. Lateral - 10.5g.

3. Vertical - 45g for duration of .10 second limited by the energy-absorber system to 25g $\pm$ 5g at the pelvic region of a 95 percentile dummy.

Because of the relatively long duration of the high loads, the seats and support structure are designed to support statically the 45g longitudinal load combined with 10.5g lateral and 25g vertical loads.

The design objective was a ductile structure with strength sufficient for the above loads.

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LOAD DIRECTION

Load directions are in agreement with the recommendations of Reference 9. Longitudinal loads are assumed to be perpendicular to the spine and vertical loads are assumed to be parallel to the spine. This conservative application of loads provides for maximum protection of the seat occupant.

TABLE 1

WEIGHT AND LOAD DATA

	Weight (lb.)	Load Due to 10.5g (lb.)	Load Due to 45g (lb.)	Load Due to 25g (lb.)
Man + Seat Bucket	318.8	3350	14,360	- -
Man + Seat Bucket + Support	360.8	3800	16,250	- -
Man (80% Effective)* + Seat Bucket + Support	320.8	- -	- -	8030

* For vertical loads, it is estimated that half of the occupant's leg weight is supported by the floor structure. Since the occupant's legs comprise approximately 40% of his total weight, 80% of his total weight is applied for vertical loads.

FRICTIONAL LOADS

The loads at the seat bucket guide rollers will develop frictional forces which tend to resist vertical travel of the seat. The maximum load at the seat guide rollers is 36,912 pounds and the minimum load at the seat guide rollers is 15,900 pounds (reference Page 24). The rolling friction of the roller system under load was computed as follows:

$$\text{Rolling Friction} = \frac{k}{r} L$$

(Page 223, Reference 11)

k = Rolling friction coefficient
k = .002 for steel on steel
k = .02 for hardwood on hardwood
k = .01 estimated for steel on aluminum alloy

r = Roller radius
r = .50 inch average
L = Roller loading

$$\text{Maximum roller friction} = \frac{.01(36,912)}{.5}$$

$$= 738 \text{ pounds}$$

$$\text{Minimum roller friction} = \frac{.01(15,900)}{.5}$$

$$= 318 \text{ pounds}$$

For the analysis of the operation load limiter, the above friction loads were used. For the analysis of the seat structure, a conservative 1,000 pound friction load was added to the supporting force of the load limiter.

LOAD LIMITER

The load limiter for this seat is rated at 4,750 pounds minimum and 5,250 pounds maximum. This rating applies throughout the stroke of the limiter.

The weight of the moving load, which is supported by the load limiter, is 278.8 pounds. This includes 118.8 pounds for the seat bucket and 160 pounds for the occupant. The 160 pound weight represents 80% of the weight of the occupant (reference Page 32).

The supporting force of the load limiter combined with roller friction will have the following limits:

Maximum supporting force = 5250 + 738

= 5988 pounds

Minimum supporting force = 4750 + 318

= 5068 pounds

Based on the above seat supporting forces, the load limiting system will operate at the following load factors.

$$\text{Load factor} = \frac{\text{Force}}{\text{Weight}}$$

$$\text{Load factor (maximum)} = \frac{5{,}988}{278.8}$$

$$= 21.4g$$

$$\text{Load factor (minimum)} = \frac{5{,}068}{278.8}$$

$$= 18.2g$$

The above load factors represent the load limiter operational limits for a 200-pound occupant. Based on the above calculations, the load limiter system will maintain the safe 25g load factor when the moving load is at least 240 pounds. Thus the seat is fulfilling its safety requirement when 121.2 pounds of the occupant's weight is acting to force the seat down.

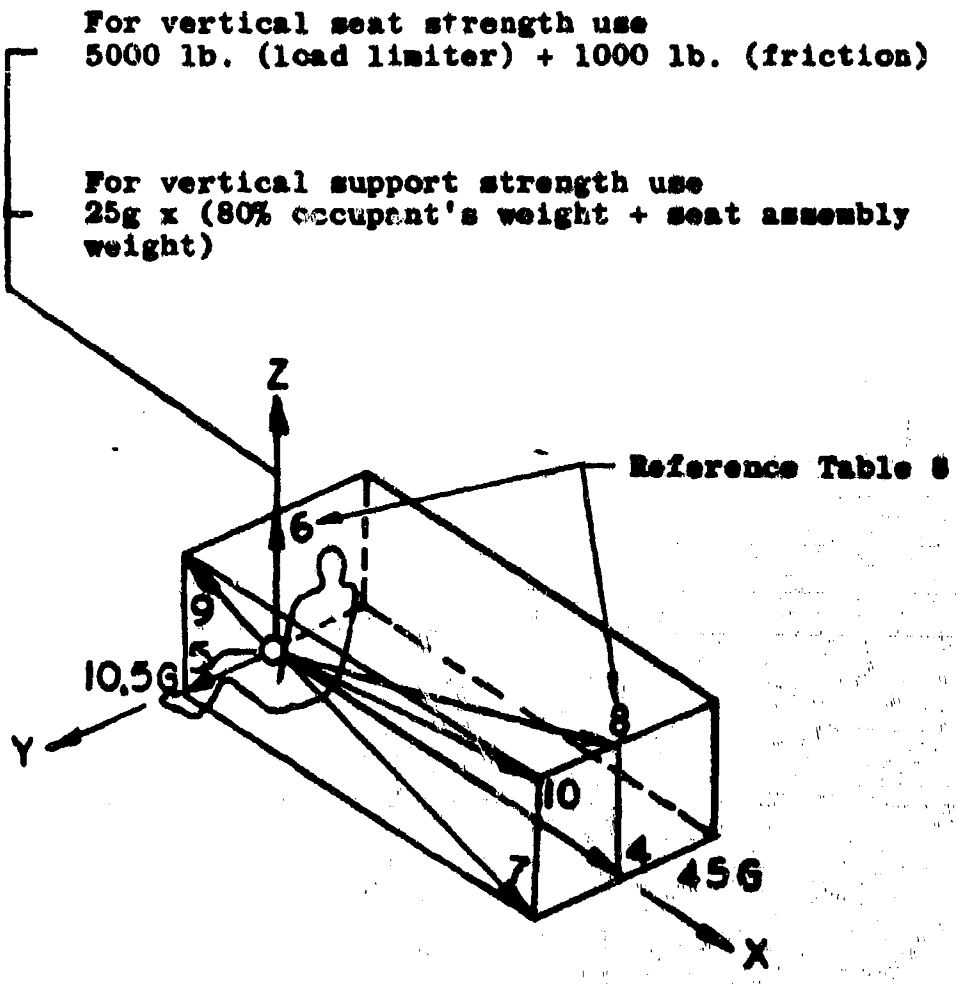


Figure 5. Seat Loads and Directions.

RESTRAINT HARNESS LOADS

Values for the restraint harness loads were calculated (reference Pages 50, 51, and 52). These values were compared with similar values derived in another investigation. (See Reference 9.) The comparison showed reasonably close agreement of load values. The slightly higher more conservative values derived (see Reference 9) were used for this analysis. These loads are listed below.

TABLE 2

RESTRAINT HARNESS LOADS

Harness Component	Load (lb.)
Shoulder Harness *	4000
Lap Belt	6000
Inverted Vee Strap	3000
Belt Tie-Down Strap	2500

* Use of chest belt for direct restraint will greatly reduce the shoulder harness loads.

TABLE 3

WEIGHT DISTRIBUTION-200-LB. MAN

	%	Weight Pounds
Whole arm and hand	5.65 x 2ea.	22.6
Whole leg and foot	19.55 x 2ea.	78.2
Head & Neck	7.9	15.8
Trunk	41.7	83.4
Total		200.0

NOTE: See Reference 3, pages 186 and 211

TABLE 4

CENTER OF GRAVITY OF SEAT BUCKET (INCLUDING TORSO SHIELD)

	Weight	x	y	z	wx	wy	wz
Back	32	3.80	0	10.80	121.5	0	346
Seat	15.7	-6.10	0	-4.70	-95.7	0	-73.7
Structure Mechanical	27	-1.40	0	6.60	-37.8	0	178
Shoulder Shield	10.65	-2.80	13.9	17.10	-29.8	148.3	182
Side Armor	8.45	-2.20	9.3	2.20	-18.5	78.6	18.5
Torso Shield	25	-8.08	0	8.50	-202	0	212
Totals	118.8				-262.3	226.9	862.8

$$\bar{x} = \frac{\Sigma wx}{\Sigma w} = -2.22$$

$$\bar{y} = \frac{\Sigma wy}{\Sigma w} = 1.92$$

$$\bar{z} = \frac{\Sigma wz}{\Sigma w} = 7.26$$

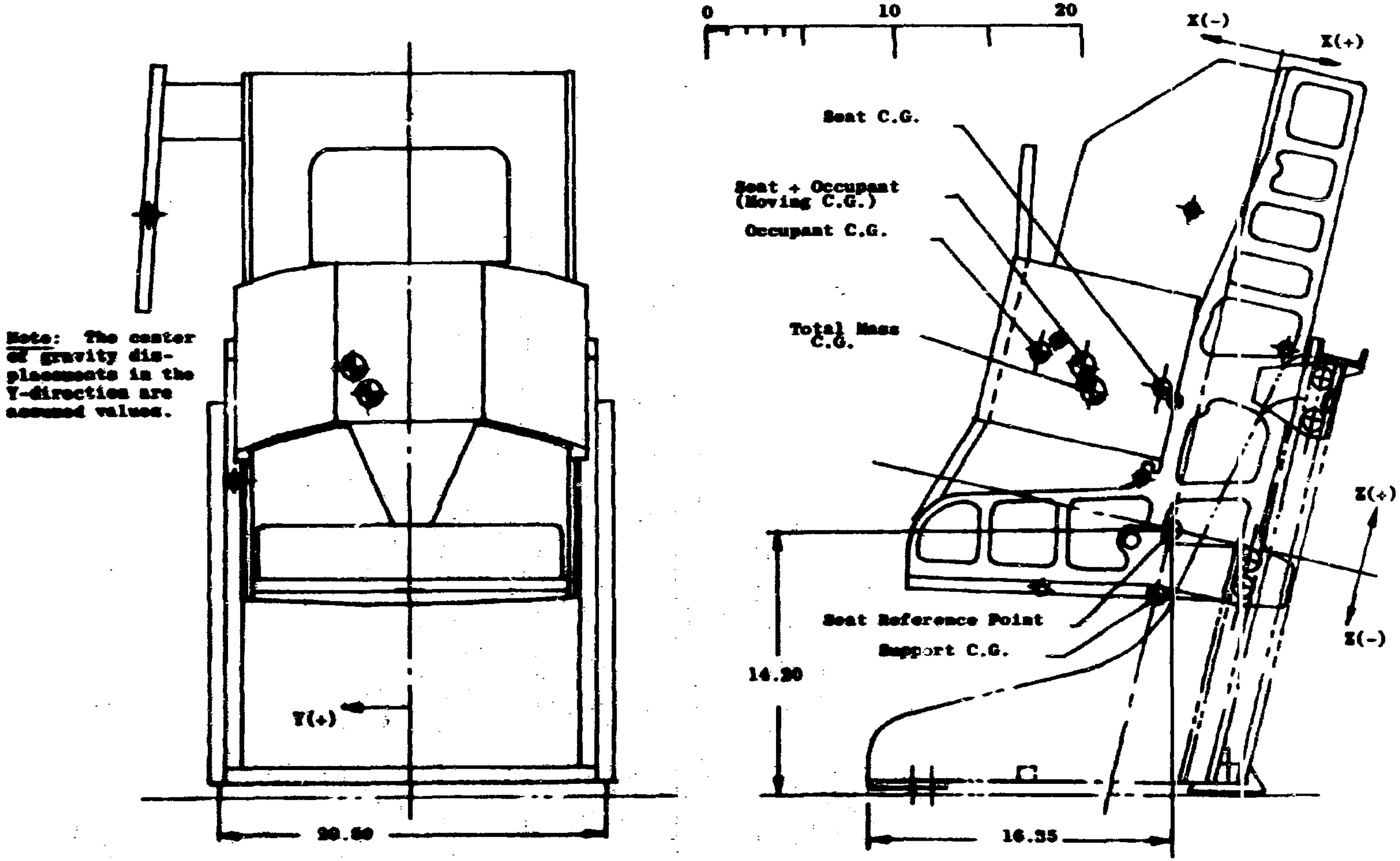


Figure 6. Seat Geometry and C. G. Data

TABLE 5*

CENTER OF GRAVITY OF SEAT AND OCCUPANT

	Weight	x	z	wx	wz
Seat	118.8	-2.22	7.26	-264	862
Man	200	-9.00	7.8	-1800	1560
Totals	318.8			-2064	2422

$\bar{x}$ = -6.48

$\bar{z}$ = 7.60

$\bar{y}$ = 3.0 (Estimated)

*Reference Figure 6

TABLE 6*

CENTER OF GRAVITY OF COMPLETE SEAT AND OCCUPANT

	Weight	x	z	wx	wz
Bucket & Occupant	318.8	-6.48	7.60	-2064	2422
Support	42	0	-3.50	0	-147
Totals	360.8			-2064	2275

$\bar{x}$ = -5.73

$\bar{z}$ = 6.3

$\bar{y}$ = 2.20 (Estimated)

*Reference Figure 6

UNIT SOLUTIONS

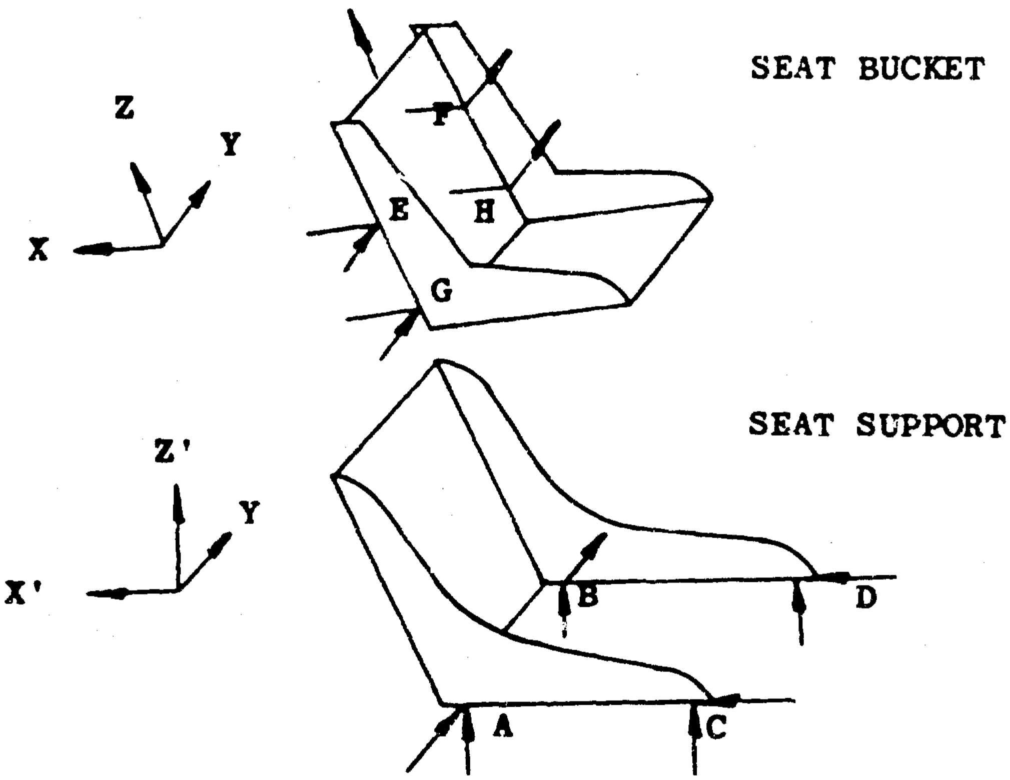


Figure 7. Reference Axes for Load Analysis.

Seat Bucket Unit Solution

P_x = -1000 Pounds in X Direction

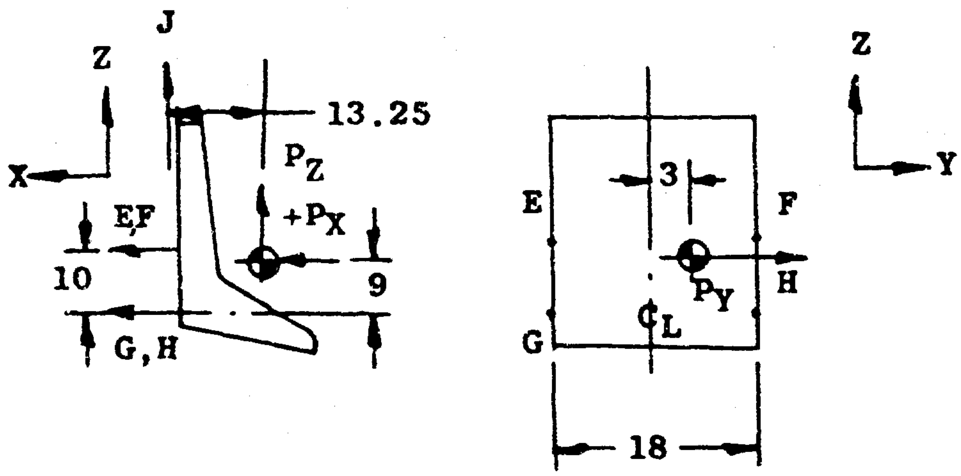


Figure 8. Geometry of Seat Bucket Loads

$\Sigma M_{GH} = 0; \quad E_x + F_x = \frac{9000}{10} = 900$ Pounds

Assume $\quad E_x = \frac{6}{18} \times 900 = 300$ Pounds

$F_x = 900 - 300 = 600$ Pounds

$\Sigma F_x = 0; \quad G_x + H_x = 100$ Pounds

$G_x = \frac{6}{18} \times 100 = 33.3$ Pounds

$H_x = 66.7$ Pounds

$P_y = 1000$ Pounds in Y Direction

$\Sigma M_{FH} = 0; \quad E_x + G_x = \frac{1000 \times 13.25}{18} = 736$ Pounds

Assume 50% of M_{FH} is reacted by E_x and F_x

Then $\quad E_x = G_x = .5 \times 736 = 368$ Pounds

$\Sigma F_x = 0; \quad F_x = H_x = -368$ Pounds

$\Sigma M_{xGH} = 0; \quad E_y + F_y = -1000 \times \frac{9}{10} = -900$ Pounds

$G_y + H_y = -100$ Pounds

F_z = 1000 Pounds in Z Direction

$\Sigma M_{GH} = 0; \quad E_x + F_x = \dfrac{100 \times 13.25}{10} = 1325$ Pounds

Assume $\quad E_x = \dfrac{6}{18} \times 1325 = 442$ Pounds

$F_x = 883$ Pounds

$\Sigma F_x = 0; \quad G_x = -442$ Pounds

$H_x = -883$ Pounds

$J = 1000$ Pounds

ΣM_x at $E = 0;$

$$1000(9) - 1000(12) + (G_y + H_y)(10) = 0$$

$G_y + H_y = 300$ Pounds

$\Sigma F_y = 0; \quad E_y + F_y = -300$ Pounds

TABLE 7

SEAT BUCKET LOADS

Location & Direction	E		F		G		H		J
Loading	x	y	x	y*	x	y	x	y**	z
P_x = 1000	300	0	600	0	33.3	0	66.7	0	0
P_y = 1000	368	0	-368	-900	368	0	-368	-100	0
P_z = 1000	442	0	883	-600	-442	0	-883	600	1000
P_x = -14360	4310	0	8620	0	479	0	958	0	0
P_y = 3350	1231	0	-1231	-3020	1231	0	-1231	-335	0
P_z = -6000	2650	0	5300	-3600	-2650	0	-5300	3600	6000
$P_x + P_y$	5541	0	7399	-3020	1710	0	273	-335	0
$P_x + P_z$	6960	0	13920	-3600	-2171	0	-4342	3600	0
$P_y + P_z$	3881	0	4069	-6620	-1419	0	-6531	3265	6000
$P_x + P_y + P_z$	8191	0	12689	-6620	- 940	0	-5027	3265	6000
Maximum	13920	*	13920	0	1710	**	1710	3600	6000
Minimum	-1231	*	-1231	-6620*	-6531	**	-6531	-335	0

* Side loads F_y are shared by E_y

** Side loads H_y are shared by G_y

Support Structure Unit Solution

(With Seat in Uppermost Position)

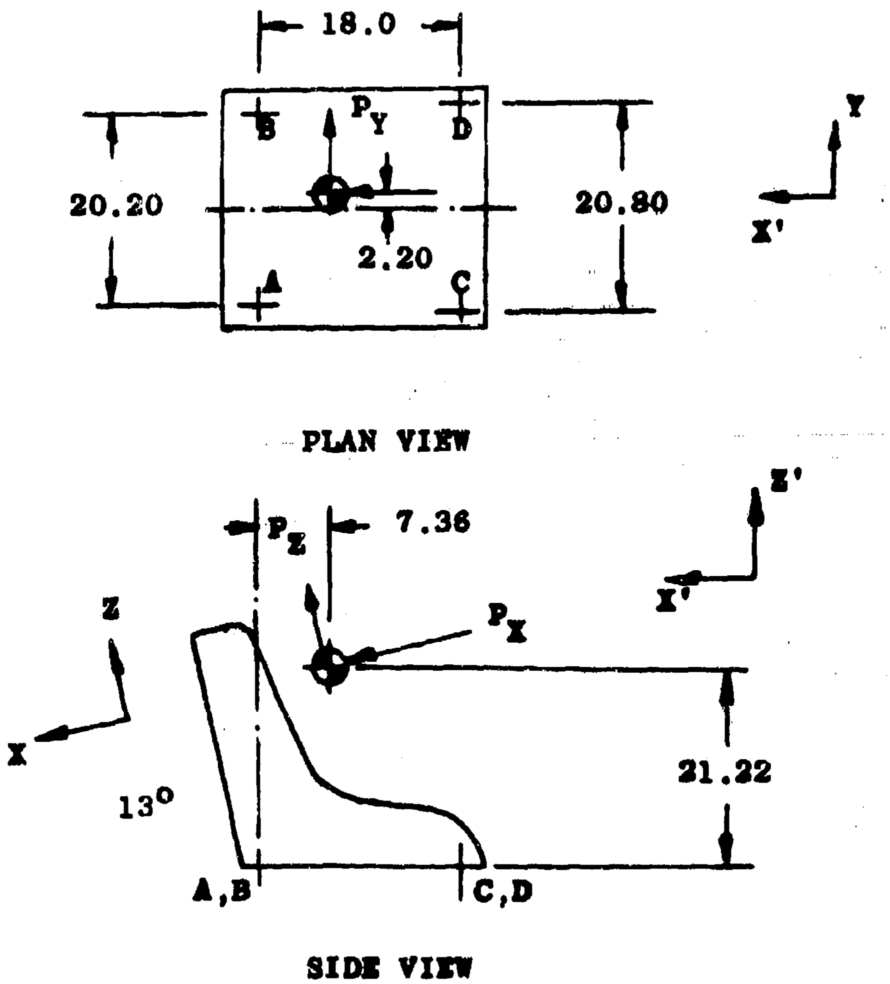


Figure 9. Geometry of Seat Support Loads.

UNIT SOLUTION

P_x = 1000 Pounds in X Direction

$\Sigma M_z'$ @ D = 0 ; $\quad C_x' = \frac{8.2}{20.8}(974.4)$

C_x' = 385 Pounds

$\Sigma M_z'$ @ C = 0 ; $\quad D_x' = \frac{12.6}{20.8}(974.4)$

D_x' = 590 Pounds

$\Sigma M_{CD} = 0$; $\quad A_z' + B_z' = \frac{-(10.64x222+21.22x974.4)}{18}$

$A_z' + B_z'$ = -1270 Pounds

Say $\quad A_z' = \frac{7.9}{20.2}$ x -1270

A_z' = -497 Pounds

B_z' = -774 Pounds

$\Sigma M_x'$ @ D = 0 ; $\quad$ -497(20.5) + (-774)(.3) + 222(8.2) +

20.8 C_z' = 0

C_z' = 414 Pounds

$\Sigma M_x'$ @ C = 0 ; $\quad$ -(497)(.3) - (-774)(20.5) - 222(12.6) -

20.8 D_z' = 0

D_z' = 626 Pounds

UNIT SOLUTION

P_y = 1000 Pounds in Y Direction

$\Sigma M_z' @ D$; $\quad C_x' = \frac{7.36 \times 1000}{20.8} = 354$ Pounds

$D_x' = -354$ Pounds

$\Sigma F_y' = 0$; $\quad A_y = B_y = 500$ Pounds

$\Sigma M_x' @ B = 0$; $\quad A_z' = \frac{-21.22 \times 1000}{20.2} = -1050$ Pounds

$B_z' = 1050$ Pounds

$D_z' = C_z' = 0$

P_z = 1000 Pounds in Z Direction

$$\Sigma M_z' \text{ @ } D = 0; \qquad C_x' = \frac{222 \times 8.2}{20.8}$$

$$C_x' = 87.5 \text{ Pounds}$$

$$\Sigma F_x' = 0; \qquad D_x' = 222 - 87.5$$

$$D_x' = 134.5 \text{ Pounds}$$

$$\Sigma M_{CD} = 0; \quad A_z' + B_z' = \frac{974.4 \times 10.64 - 222 \times 21.22}{18}$$

$$A_z' + B_z' = 313 \text{ Pounds}$$

Say

$$A_z' = \frac{(7.9)(313)}{20.2}$$

$$A_z' = 122 \text{ Pounds}$$

$$B_z' = 191 \text{ Pounds}$$

$$\Sigma M_x' \text{ @ } D = 0; \quad 122(20.5) + 191(.3) + (-974.4)(8.2) +$$

$$20.8\, C_z' = 0$$

$$C_z' = 261 \text{ Pounds}$$

$$\Sigma M_x' \text{ @ } C = 0; \quad -(122)(.3) - 191(20.5) - (-974.4)(12.6) -$$

$$20.8\, D_z' = 0$$

$$D_z' = 398 \text{ Pounds}$$

TABLE 8

FLOOR ATTACHMENT LOADS

Location & Direction		A		B		C		D	
	Loading	y	z'	y	z'	x'	z'	x'	z'
1	P_x = - 1000	0	- 497	0	- 774	385	414	590	626
2	P_y = 1000	- 500	- 1050	- 500	- 1050	354	0	- 354	0
3	P_z = - 1000	0	122	0	191	87.5	261	134.5	398
4	P_x = -16350	0	- 8060	0	-12560	6260	6730	9600	10180
5	P_y = 3800	-1900	- 3990	-1900	+ 3990	1345	0	-1345	0
6	P_z = - 8030	0	980	0	1532	704	2095	1080	3200
7	P_x+P_y (4+5)	-1900	-12050	-1900	- 8570	7605	6730	8255	10180
8	P_x+P_z (4+6)	0	- 7080	0	-11038	6964	8825	10680	13380
9	P_y+P_z (5+6)	-1900	- 3010	-1900	+ 5522	2049	2095	- 265	3200
10	$P_x+P_y+P_z$ (4+5+6)	-1900	-11070	-1900	- 7038	8309	8825	9335	13380
11	Maximum	0	980	0	5522	8309	8825	10680	13380
12	Minimum	-1900	-12050	-1900	-12560		0	-1345	0
13	Maximum For P_y		5522	0	5522	10680	13380	10680	13380
14	Minimum + or -		-12560	-1900	-12560	-1345	0	-1345	0

UPPER TORSO RESTRAINT; 45G LOAD IN X-DIRECTION

Chest Strap Plus Shoulder Harness

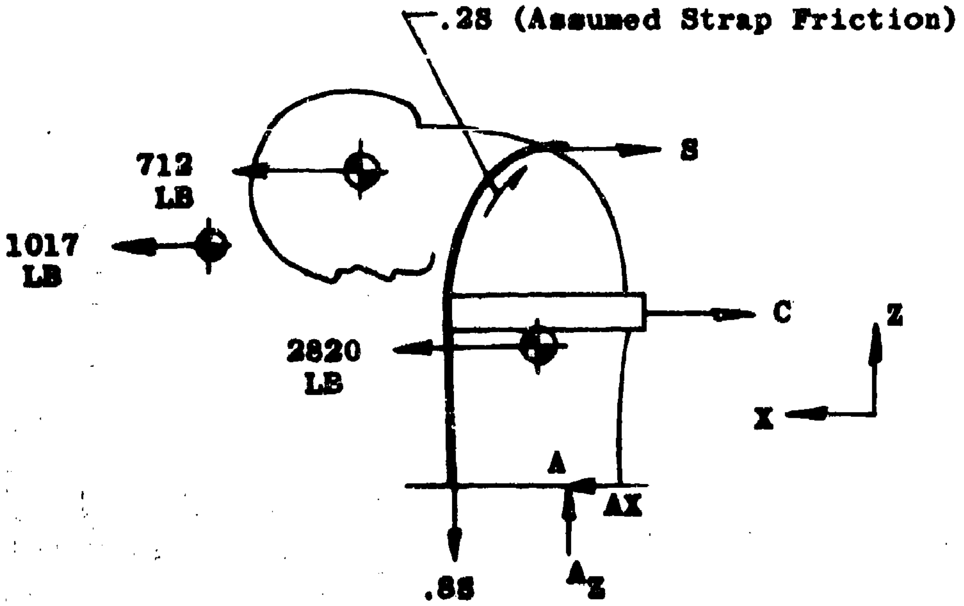


Figure 10. Upper Torso Restraint Loads from Chest Strap and Shoulder Harness.

Say

$$A_X = 0$$

$$\Sigma F_X = 0; \qquad 1017 + 712 + 2820 - S - C = 0$$

$$C + S = 4549$$

$$\Sigma F_Z = 0; \qquad A_Z = .8S$$

$$\Sigma M_A = 0;$$

$$16.5 \times 712 = 11{,}750$$

$$12.6 \times 1017 = 12{,}800$$

$$7.1 \times 2820 = \underline{20{,}000}$$

$$44{,}550 + 6(.8S) - 17.50S - 9C = 0$$

$$C + 1.41S = 4960$$

Combining:

$$.41S = 411$$

$$S = 1000 \text{ Pounds}$$

$$C = 4549 - 1000: \qquad C = 3549 \text{ Pounds}$$

Shoulder Harness Only

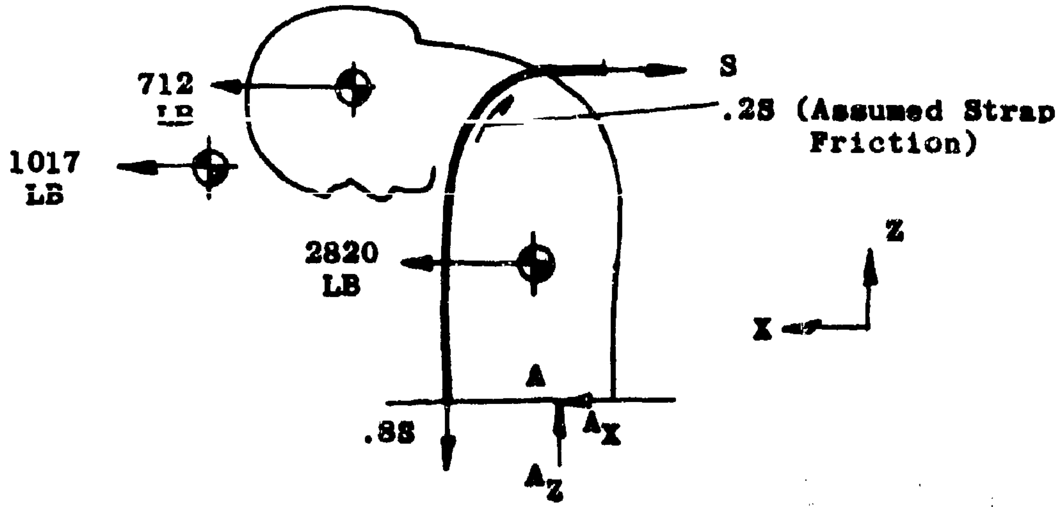


Figure 11. Upper Torso Restraint Loads from Shoulder Harness Only.

$$\Sigma M_A = 0; \quad 44{,}550 + 6(.8S) - 17.50S = 0$$

$$12.70S = 44{,}550 \text{ Pounds}$$

$$S = 3530 \text{ Pounds}$$

$$\Sigma F_z = 0; \quad A_z = .8\,S$$

$$A_z = 2820 \text{ Pounds}$$

Upper Torso Weight = 101 Pounds
Spinal Compression = 2820 Pounds

Load is induced by 45g forward load. Equivalent vertical acceleration is:

$$a' = \frac{P}{W} \qquad a' = \frac{2820}{101} \qquad a' = 28g$$

Applied vertical loads and induced spinal loads must be superimposed: With an estimated 20g vertical load (safe load per Reference 5), and a 28g induced load, then the effective total spinal load is 48g. A load of this magnitude is not tolerable per Reference 5.

LOWER TORSO RESTRAINT; 45G LOAD IN X-DIRECTION

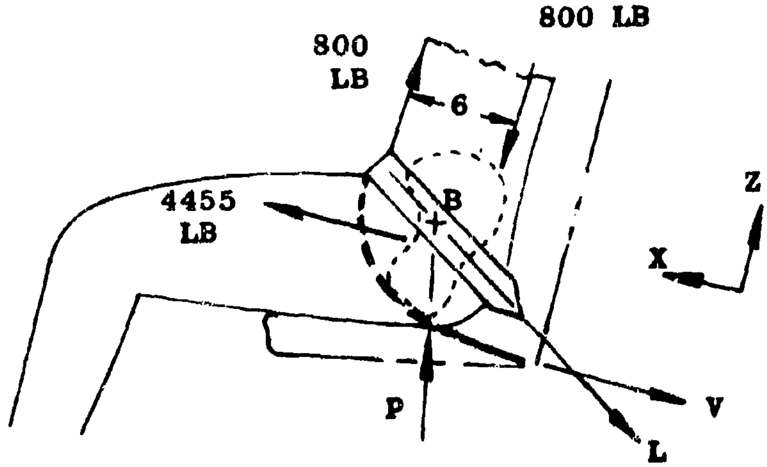


Figure 12. Lower Torso Restraint Loads.

$$\Sigma M_B = 0; \qquad -5\,V + 4455\,(1.5) + 800\,(6) = 0$$

$$5\,V = 11{,}000$$

$$V = 2200$$

$$\Sigma F_x = 0; \qquad -.86\,L - V + .15\,P + 4455 = 0$$

$$-.86\,L + .15\,P = 2255$$

$$\Sigma F_z = 0; \qquad -.50\,L + .99\,P = 0$$

$$-.50\,L + .09\,P = -1310$$

$$\text{Combining:} \qquad .90\,P = 1310$$

$$P = 1455$$

$$L = 2880$$

APPENDIX II

STRESS ANALYSIS

The loads derived in Appendix I were applied to the detail components, and stresses were determined. Typical examples of the procedures used are included in this section.

The objective of this seat design was a ductile structure which would sustain the applied loads. These loads are the design ultimate loads developed in Appendix I with no superimposed safety factor.

Stress levels are intentionally high to minimize weight. This approach is justified because higher than normal ultimate stresses are predicted with the dynamic load application and because many of the critical components are relieved as the seat travels through its energy-absorption stroke.

Routine procedures were used and simplifying assumptions used in redundant situations are noted in the text.

DETAIL STRESS ANALYSIS

Lap Belt

Although lap belt calculated loads are relatively low (reference Page 52), conservative loads will be applied.

Load in belt = 6000 pounds (Page 36)

Say P = 4000 pounds each end

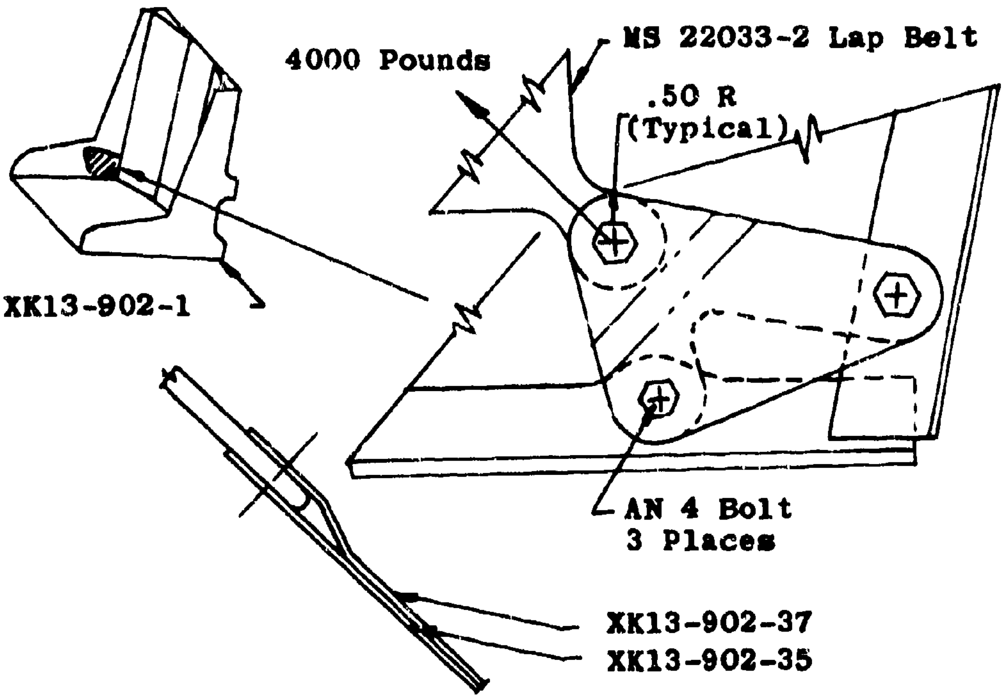


Figure 13. Lap Belt Attachment Details.

Belt Attaching Bolt

2000 pounds per lug

Bolt shear allowable = 3680 pounds (Reference 1)

Margin of Safety (M.S.) = .84

Bearing in Lug:

$$f_{br} = \frac{2000}{.25 \times .04}$$

$$f_{br} = 200{,}000 \text{ p.s.i.}$$

$$F_{bru} = 251{,}000 \text{ p.s.i.}$$

$$M.S. = .255$$ (Reference 1)

Shear of Lug:

$$f_s = \frac{2000}{2 \times .37 \times .04}$$

$$f_s = 67{,}500 \text{ p.s.i.}$$

$$F_{su} = 82{,}000 \text{ p.s.i.}$$ (Reference 1)

$$M.S. = .213$$

Lap Belt Tie

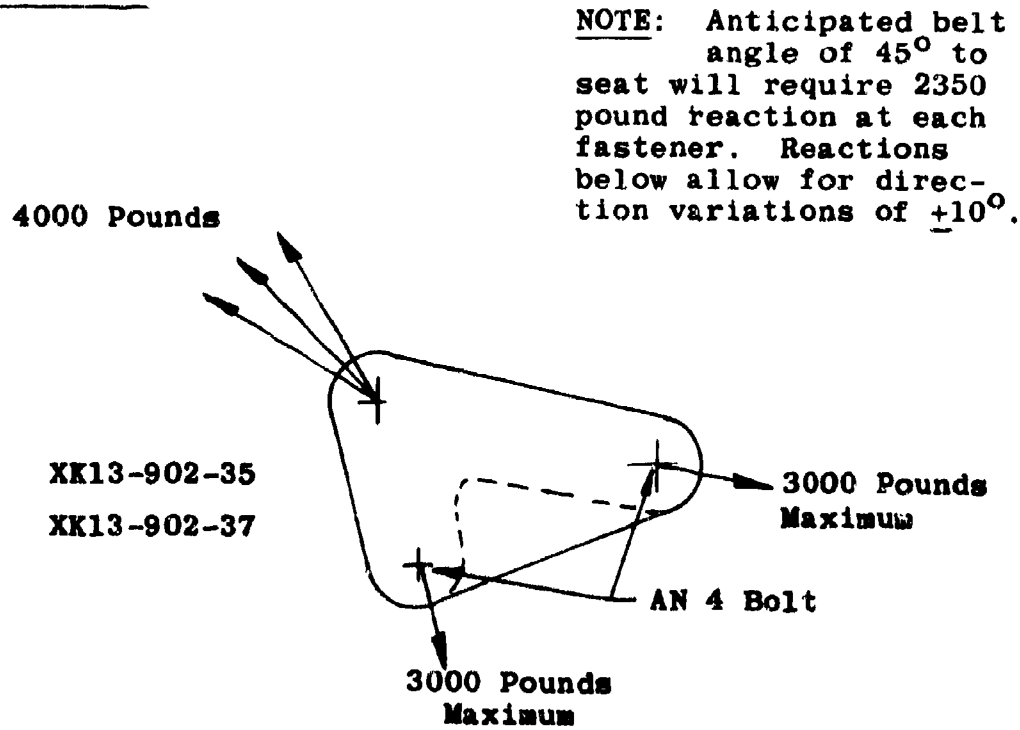


Figure 14. Lap Belt Attachment Plate.

Seat Lug Bolt Shear

Load = 3000 pounds

Ps all = 3680 pounds (Reference 1)

M.S. = .225

Bearing in Seat Lug

$$f_{br} = \frac{3000}{.25 \times .08}$$

$$f_{br} = 150{,}000 \text{ p.s.i.}$$

$$F_{bru} = 251{,}000 \text{ p.s.i.} \quad \text{(Reference 1)}$$

M.S. = .67

Chest Belt

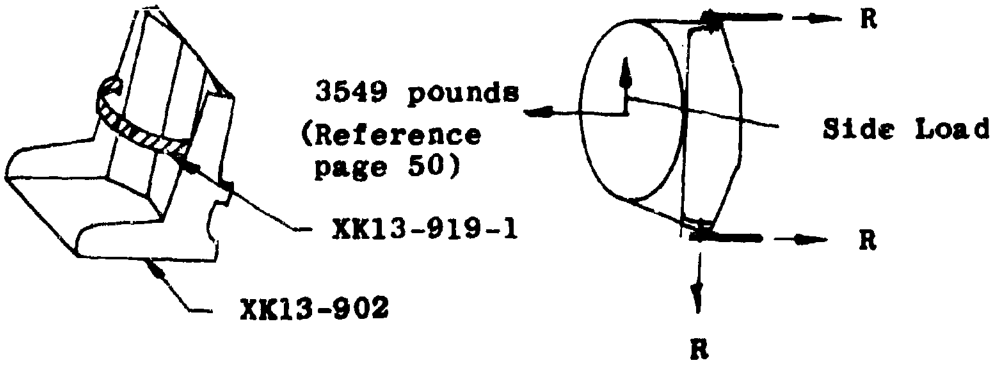


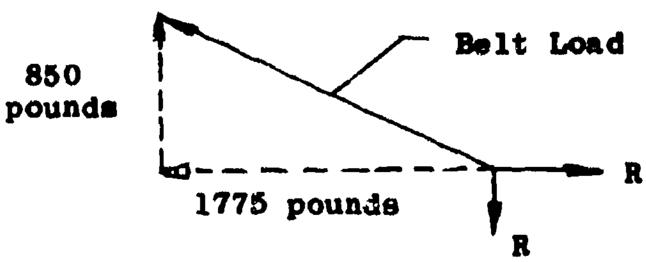
Figure 15. Chest Belt Loading.

Conservatively, the side load is assumed to be 80% of upper body (head, neck, arms, upper torso) side load.

Upper body weight = 101 pounds

Side load = 101 x 10.5g

Belt side load = 850 pounds



Belt end load = 1960 pounds

This belt is fabricated to details of Specification MIL-B-6703 and has a breaking strength of 4500 pounds loop load.

$$\text{Belt M.S.} = \frac{4500 \times \frac{1}{2}}{1960} - 1 = .15$$

Bending in Seat Upper Cross Beam

Shoulder harness capacity - 4000 pounds (reference page 36)

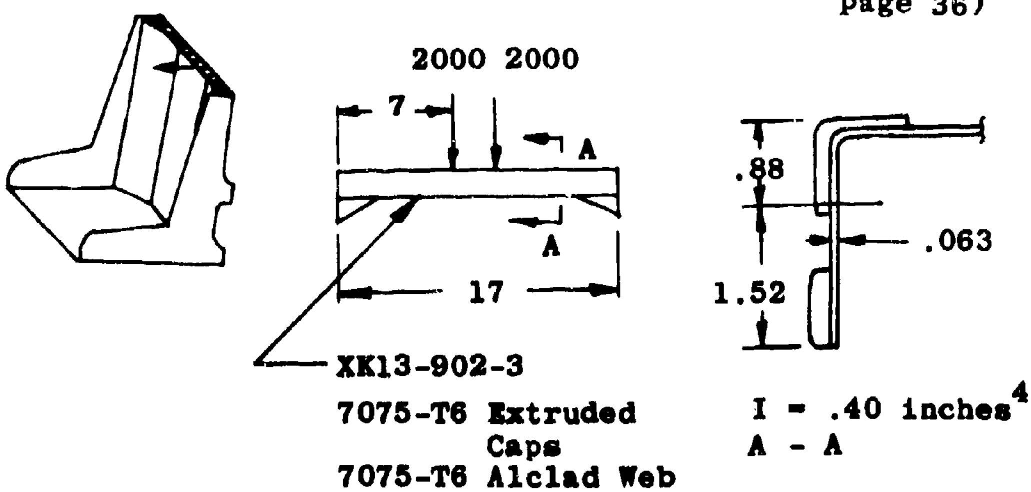


Figure 16. Seat Upper Cross Beam Loading.

$$M = 2000(7)$$

$$M = 14{,}000 \text{ inch pounds}$$

$$f_c = \frac{14{,}000(.88)}{.40}$$

$$f_c = 30{,}800 \text{ p.s.i.}$$

$$F_{cr} \text{ based on } {}^b/_t = 8$$

$$F_{cr} = 55{,}000 \text{ p.s.i.}$$

$$R_c = .58$$

$$f_t = \frac{14{,}000(1.52)}{.40}$$

$$f_t = 53{,}200 \text{ p.s.i.}$$

$$F_{tu} = 77{,}000 \text{ p.s.i.}$$

$$R_t = .69$$

Shear in Seat Upper Cross Beam

$$V = 2000 \text{ pounds}$$

$$\text{Area} = .063 \times 1.75$$

$$\text{Area} = .110$$

$$f_s = 18{,}200 \text{ p.s.i.}$$

$$F_s = 30{,}000 \text{ p.s.i.}$$ (Reference 13 Page 410)

$$R_s = \frac{18{,}200}{30{,}000}$$

$$R_s = .603$$

$$R_T = .69 \text{ (from bending in beam)}$$

$$\text{M.S.} = \frac{1}{\sqrt{.603^2 + .69^2}} - 1$$

$$\text{M.S.} = \frac{1}{\sqrt{.363 + .476}} - 1$$

$$\text{M.S.} = .092$$

Attachment of Upper Beam to Seat Side

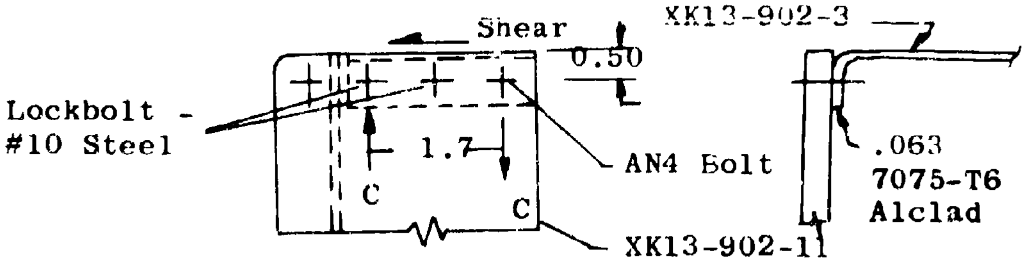


Figure 17. Attachment of Seat Upper Beam to Seat Side.

Assume Shear = 2666 pounds (2/3 shoulder harness capacity)

Assume 1000 pound/fastener shear load

Moment in joint:

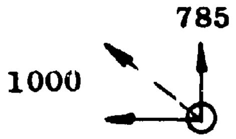
$$M = .5(2666) = 1333 \text{ in. lb.}$$

Couple to React Moment:

$$C = \frac{M}{1.7} = \frac{1333 \text{ in. lb.}}{1.7 \text{ in.}}$$

$$C = 785 \text{ pounds}$$

Load on forward fastener:



Resultant shear = 1270 pounds

Shear Allowable = 2000 pounds (Reference 1)

Bearing Allowable

F_{bru} = 14,500 p.s.i. (Reference 1)

P_{br} = 14,500(.19)(.063)

P_{br} = 1735 pounds

$$M.S. = \frac{1735}{1270} - 1$$

M.S. = .365

Seat Bottom Bending Strength

The material is composite armor. The backing material is .44 inch thick.

The properties of this backing material, supplied by the manufacturer, are as follows:

Bending Modulus	25,000 p.s.i.
Modulus of Elasticity in Bending	1,700,000 p.s.i.
Compressive Strength (Edgewise)	12,600 p.s.i.
Tensile Strength	33,000 p.s.i.

These values are in general agreement with low strength fiberglass-epoxy laminates of MIL-HDBK-17.

Primary loading is the normal load from the occupant whose weight is 80 percent effective for vertical accelerations.

$$P = .8 \times 200 \times 25g$$

$$P = 4000 \text{ pounds}$$

Add load induced by lateral load = 1455 pounds (Reference Page 52)

5455 pounds

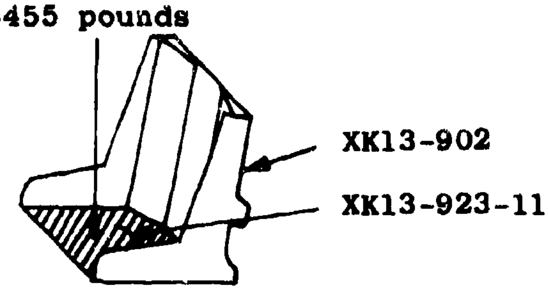


Figure 18. Seat Bottom Loading.

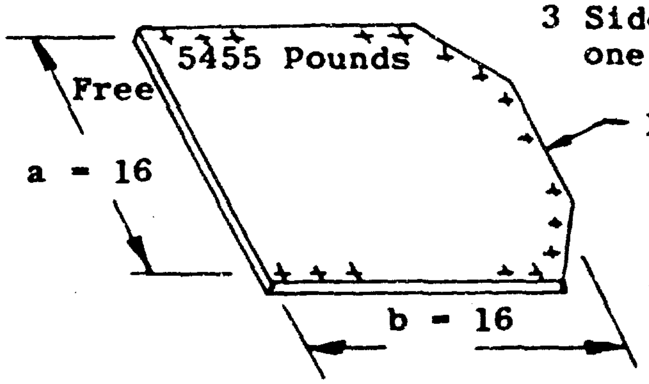


Figure 19. Seat Bottom Load Distribution.

Deflection under Load and Bending Stress:

(From reference 14, Page 206)

$$Y_{max} = .140 \frac{Wb^4}{Et^3}$$

$$Y_{max} = \frac{.140 \times 5455 \quad (16)^2}{1,700,000 \quad (.44)^3}$$

$$Y_{max} = 1.39 \text{ inches}$$

$$\text{Max S} = \frac{.67\ Wb^2}{t^2}$$

$$t = .44 \text{ (backing only)}$$

$$\text{Max S} = \frac{.67 \times 5455}{.44^2}$$

$$\text{Max S} = 18,900 \text{ p.s.i.}$$

$$F_b = 25,000$$

$$\text{M.S.} = \frac{25,000}{18,900} - 1 = .32$$

Seat Bottom Connections

Screws:

Say that the position of the man applies one-half of the 5455-pound load to a 9-inch width of edge connection.

$$\text{Unit load along edge} = \frac{.5 \times 5455}{9} = 330 \text{ pounds per inch}$$

At 1.5-inch spacing,

Load per screw = 500 pounds

Connecting Angles:

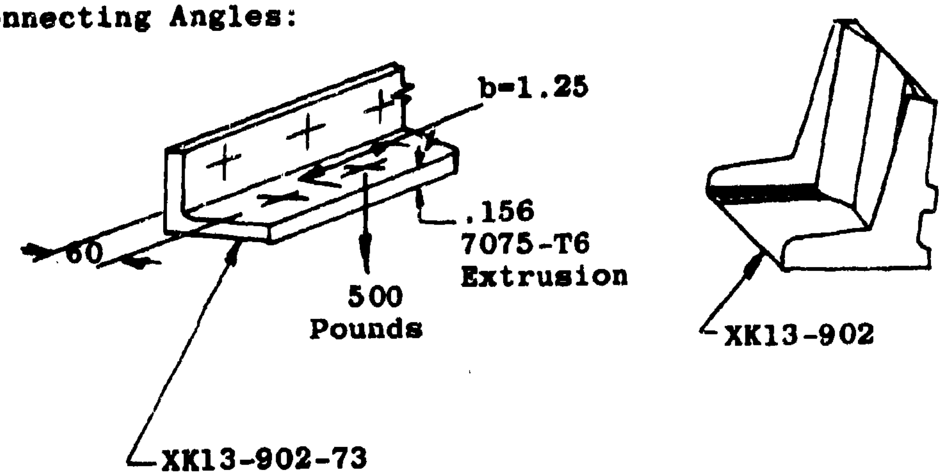


Figure 20. Seat Bottom Connecting Angle.

$$\text{Moment} = .6 \times 500$$

$$= 300 \text{ inch pounds}$$

$$f_b = \frac{6M}{bt^2}$$

$$f_b = \frac{300(6)}{1.25(.156)^2}$$

$$f_b = 59{,}200 \text{ p.s.i.}$$

$$F_{tu} = 75{,}000 \text{ p.s.i.} \quad \text{(Reference 1)}$$

Bearing on Sheet:

$$f_{br} = \frac{P}{A}$$

$$f_{br} = \frac{500}{.156(.190)}$$

$$f_{br} = 16{,}500 \text{ p.s.i.}$$

M.S. is ample.

Seat to Angle Fasteners:

AN 525-10 screws

Load = 500 pounds (tension)

P_t = 2210 pounds (Reference 1)

$$M.S. = \frac{2210}{500} - 1$$

M.S. = 3.42

Seat Bucket Upper Rollers

The critical load in X direction is 13,920 pounds (reference Table 7).

Two rollers are used at each roller bracket. The bracket is designed with a single attaching bolt which allows bracket rotation to equalize the roller loads.

$$\text{Roller load} = \frac{13{,}920}{2}$$

$$\text{Roller load} = 6960 \text{ pounds}$$

Use McGill Camrol CFH-$1\frac{1}{8}$S

Aircraft Static Capacity = 9180 pounds (reference McGill catalog)

$$\text{M.S.} = \frac{9180}{6960} - 1$$

$$\text{M.S.} = .315$$

Although loading is extreme, rolling capability for three revolutions (total travel under load) is predicted.

Track Contact Stress:

Steel Roller

7075-T652 Track

Roller Load = 6960 pounds

Roller Width = .62

$$\text{Unit Roller Load } p = \frac{6960}{.62}$$

$$p = 11{,}210 \text{ pounds per inch}$$

From reference 14, Page 288, stress due to pressure between elastic bodies, Case 4 cylinder on flat plate:

$$\text{Max } S_c = .798 \sqrt{\dfrac{p}{D \left(\dfrac{1-\nu^2}{E_1} + \dfrac{1-\nu^2}{E_2} \right)}}$$

$$S_c = .798 \sqrt{\dfrac{11{,}210}{1.125 \left(\dfrac{1-(.26)^2}{29 \times 10^6} + \dfrac{1-(.36)^2}{10 \times 10^6} \right)}}$$

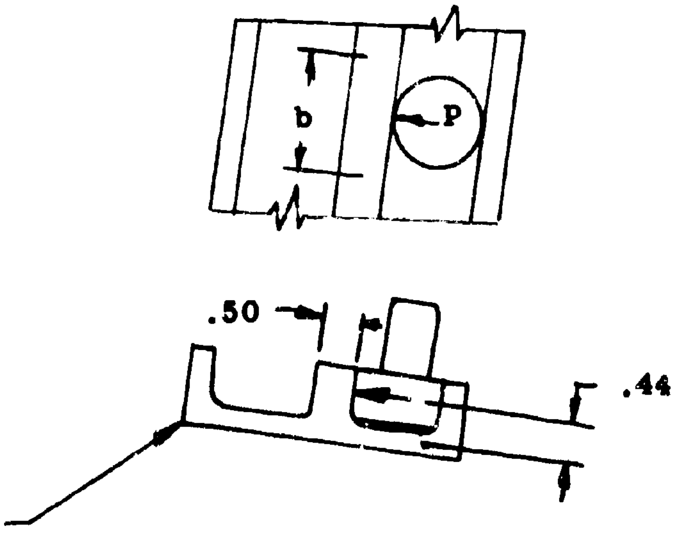
$$S_c = .798 \times \frac{10^4}{3.452} \sqrt{\frac{11{,}210}{1.125}}$$

$$S_c = 231{,}000 \text{ p.s.i.}$$

This is high for material with F_{bru} equaling 131,000 p.s.i., but some yielding will enlarge the bearing contact area, reduce the contact stress and permit survival.

Track Flange Bending

For each upper roller, P = 6960 pounds (reference Page 66)



7075 T652 Aluminum Alloy

Figure 21. Track Flange Loading.

Say b effective = 1.25 inches

$$M = .44(6960)$$

$$= 3060 \text{ inch pounds}$$

$$f_b = \frac{6M}{bt^2}$$

$$f_b = \frac{6(3060)}{1.25(.50)^2}$$

$$f_b = 59{,}000 \text{ p.s.i.}$$

$$F_{tu} = 70{,}000 \text{ p.s.i.} \text{(Reference 1)}$$

$$F_b = 1.25\ (70{,}000)$$

$$F_b = 87{,}500 \text{ p.s.i.}$$

$$R_b = .675$$

Upper Roller Bracket Loading

From Table 7, the loads in the area of the upper roller brackets are shown below:

Total side load = 6620 pounds

Apply 60 percent of side load to critical side.

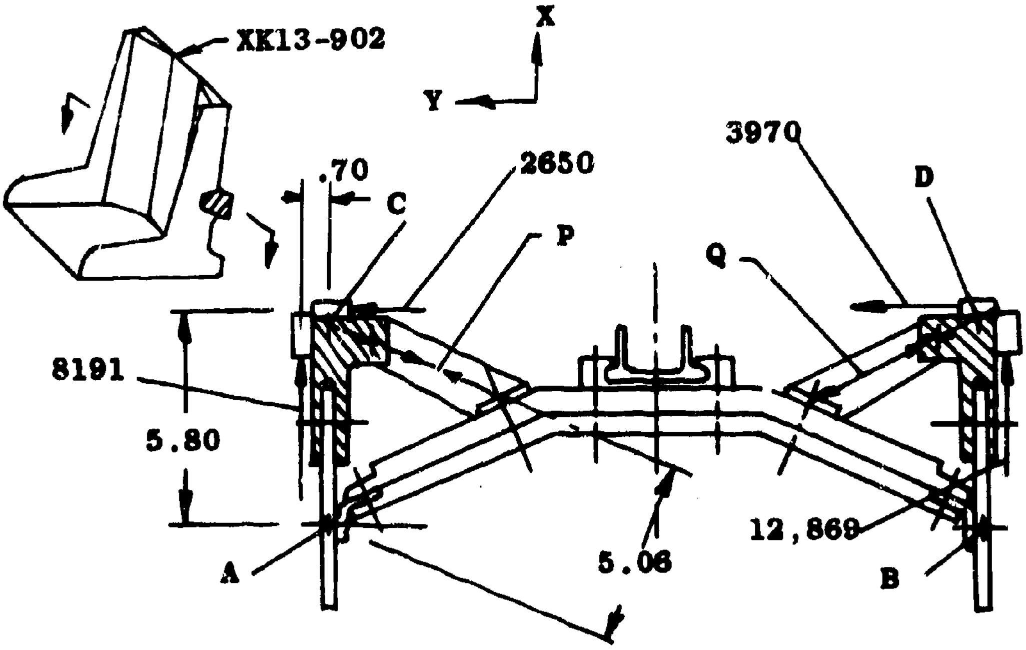


Figure 22. Seat Upper Roller Bracket Loading.

Calculate P and P_x and P_y:

Say AC is free body, $\Sigma M_A = 0$

$8191(.7) - 2650\ 5.8 + 5.06\ P = 0$

$5.06\ P = 9960$

$P = 1908$ **Tension**

$P_x = .432\ P$

$P_x = 823$ **pounds**

$P_y = .904\ P$

$P_y = 1720$ **pounds**

Calculate Q and Q_x and Q_y:

Say BD is free body; $\Sigma M_B = 0$

$$-12,869(.7) - 3970(5.8) + 5.06Q = 0$$

$$5.06Q = +32,010$$

$$Q = 6340 \text{ pounds compression}$$

$$Q_x = .432\ Q$$

$$Q_x = 2735 \text{ pounds}$$

$$Q_y = .904\ Q$$

$$Q_y = 5720 \text{ pounds}$$

Calculate A_y:

(AC is free body) $\Sigma M_C = 0$

$$-2650 \times .2 + 8191(.7) - 5.6\ A_y = 0$$

$$5.6\ A_y = 5190$$

$$A_y = 926 \text{ pounds}$$

Calculate B_y:

(BD is free body) $\Sigma M_D = 0$

$$-12,869(.7) - 3970(.2) + 5.6\ B_y = 0$$

$$5.6\ B_y = 9804$$

$$B_y = 1752 \text{ pounds}$$

Seat Back Loads due to Energy Absorber Loads

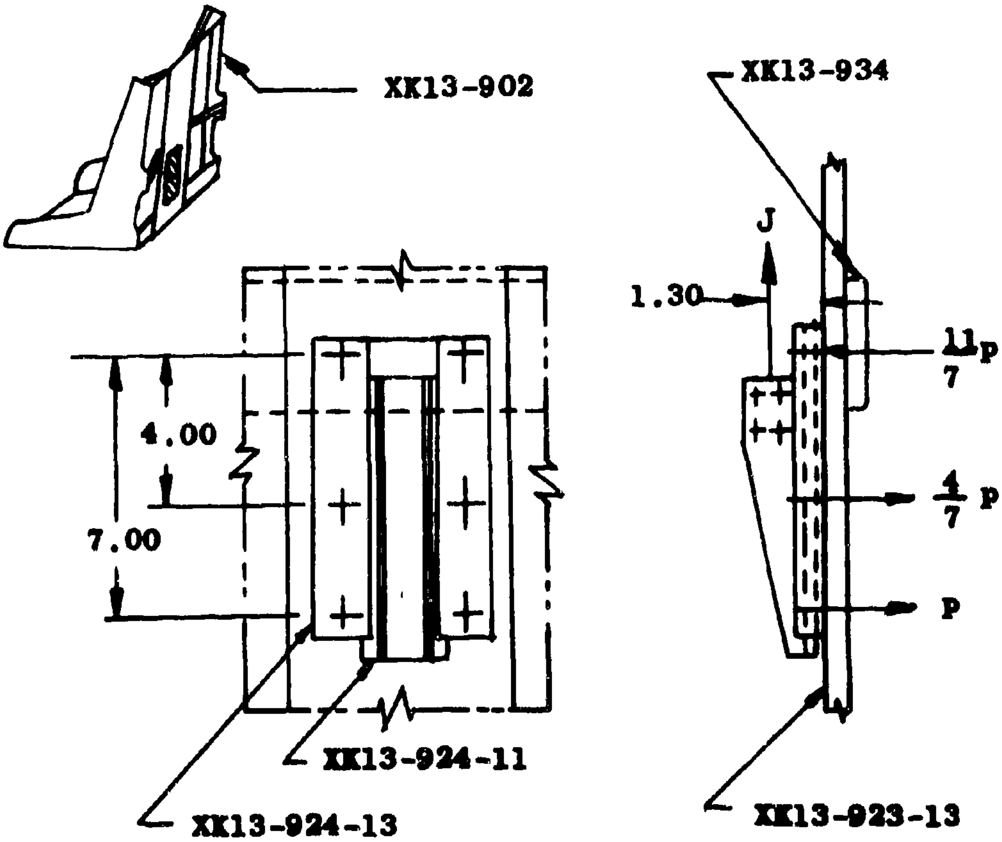


Figure 23. Seat Back Loading due to Energy Absorber Loads.

$$J = 6000 \text{ (reference Table 7)}$$

$$M = 0$$

$$7\,P\;4(\tfrac{4}{7})P - 1.3 \times 6000 = 0$$

$$\frac{65}{7}\,P = 7800$$

$$P = 840 \text{ Pounds}$$

$$\frac{4}{7}\,P = 480 \text{ Pounds}$$

$$\frac{11}{7}\,P = 1320 \text{ Pounds}$$

Loads on Back at Level of Upper Rollers

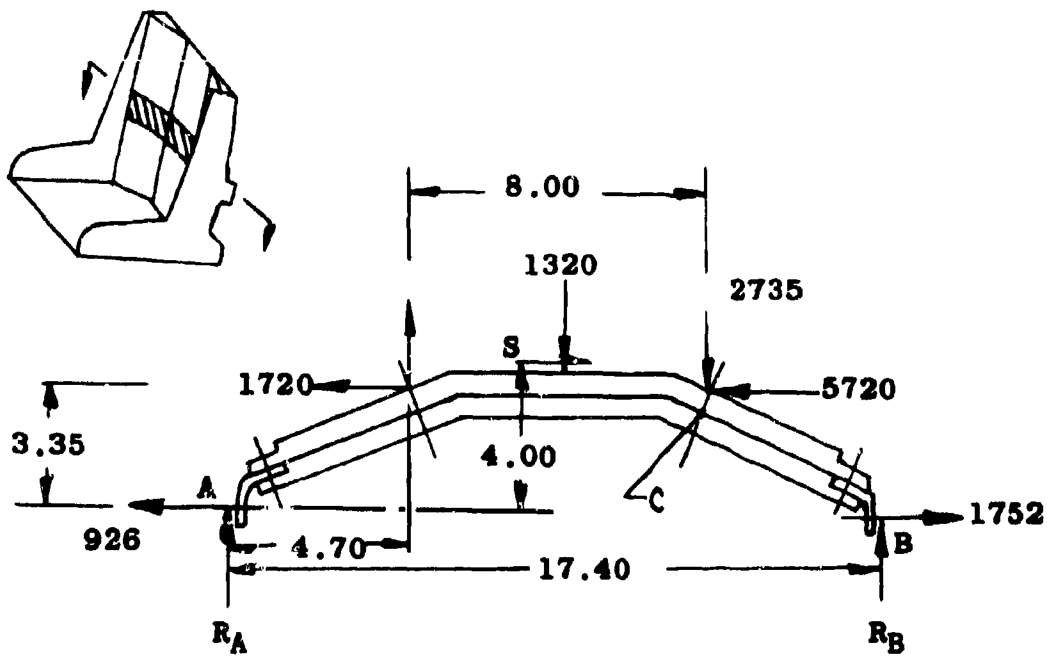


Figure 24. Loading of Seat Back at Upper Rollers.

$$\Sigma F_y = 0$$

$$-926 - 1720 - 5720 + 1752 + S = 0$$

$$S = 6614 \text{ pounds}$$

$$\Sigma M_A = 0$$

$$-1720(3.35) - 823(4.7) + 1320(817) + 2735(12.7)$$

$$-5720(3.35) - 1740R_B + 6614(4.00) = 0$$

$$17.4\ R_B = 43{,}850$$

$$R_B = 2520 \text{ pounds}$$

Bending at C; $M = 1752(3.35) + 2520(4.70)$

$$M = 17{,}710 \text{ inch-pounds}$$

Check Back Panel and Rib for Bending

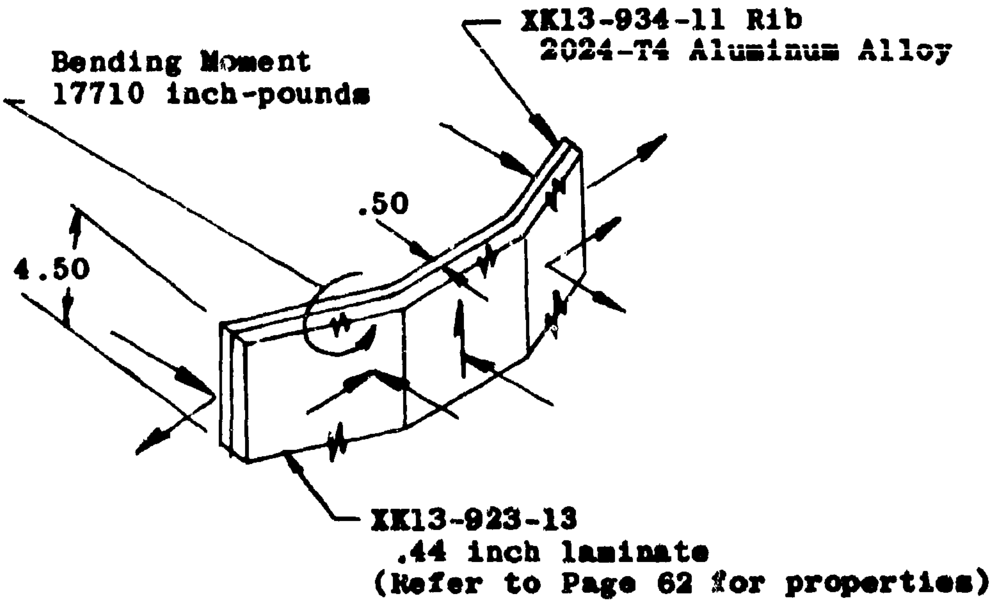


Figure 25. Bending of Seat Back and Reinforcing Rib.

Assume rib and back bend independently with load sharing in proportion to relative stiffness:

$$E \text{ fiberglass} = 1,700,000$$

$$E \text{ aluminum} = 10,500,000$$

Say I of both fiberglass and 2024 reinforcing rib are equal for bending about Z axis:

Fiberglass carries 13.9% of load.

Aluminum alloy rib carries 86.1% of load bending stresses in rib:

$$M = 17,710 \text{ inch-pounds}$$

$$.861\ M = 15,250 \text{ inch-pounds}$$

$$f_b = \frac{6(15,250)}{4.50(.5)^2}$$

$$f_b = 81,400 \text{ p.s.i.}$$

$$F_b = 1.25\ F_{tu}$$

$$F_b = 81,300 \text{ p.s.i.}$$

Slight negative margin is compensated by beneficial effect of composite beam action which was conservatively neglected.

Bending stress in fiberglass laminate:

$$.139\ M = 2470 \text{ inch-pounds}$$

$$\text{effective width} = 5.2 \text{ inches}$$

$$f_b = \frac{6(2470)}{5.2\ (.44)^2}$$

$$f_b = 14,800 \text{ p.s.i.}$$

Upper Roller Fitting

Conservatively, say socket action of roller shaft reacts overhang moment.

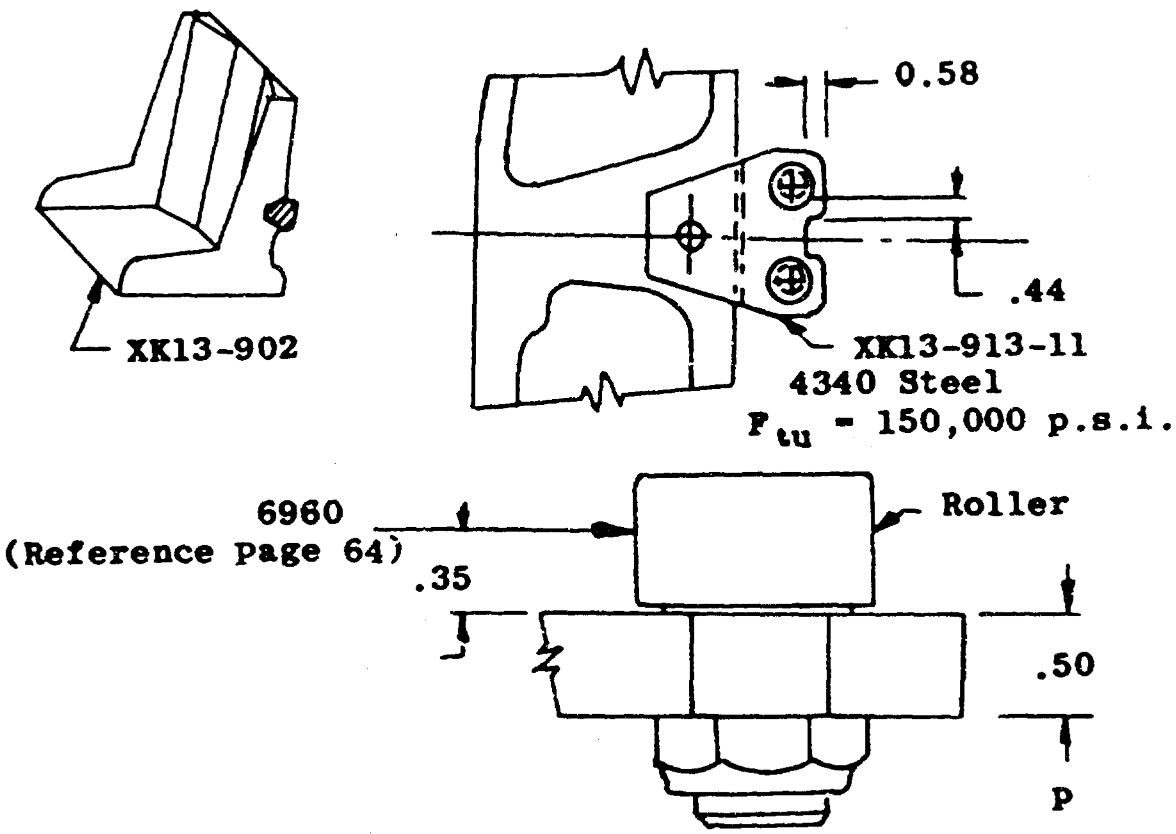


Figure 26. Upper Roller Fitting.

Overhang moment:

$$M = .35\ (6960)$$

$$M = 2440 \text{ inch-pounds}$$

By the use of Reference 19, the socket stresses may be solved as follows:

$$M = 2440 \text{ inch-pounds}$$

$$S = 6960 \text{ pounds}$$

$$L = .50 \text{ inch}$$

$$t_1 = .44 \text{ inch}$$

$t_2 = .58$

$$\frac{M}{SL} = \frac{2440}{6960(.5)}$$

$$\frac{M}{SL} = .70$$

Maximum unit loads:

$K_1 = 8.20$ (Reference 19)

$$W_1 = \frac{K_1 S}{L}$$

$$W_1 = \frac{8.20 \times 6960}{.50}$$

$W_1 = 114{,}000$ pounds per inch

Bearing in socket:

$$f_{br} = \frac{W}{D}$$

$$f_{br} = \frac{114{,}000}{.625}$$

$f_{br} = 182{,}500$ p.s.i.

$F_{bru} = 219{,}000$ p.s.i.

M.S. = .20

Tension in fitting due to socket load:

$$f_t = \frac{W}{2t_1}$$

$$f_t = \frac{114,000}{.88}$$

$$f_t = 129,300 \text{ p.s.i.}$$

$$F_{tu} = 150,000 \text{ p.s.i.}$$

$$M.S. = .16$$

Shear in fitting due to socket load:

$$f_s = \frac{W}{2t_2}$$

$$f_s = \frac{114,000}{2(.58)}$$

$$f_s = 98,500 \text{ p.s.i.}$$

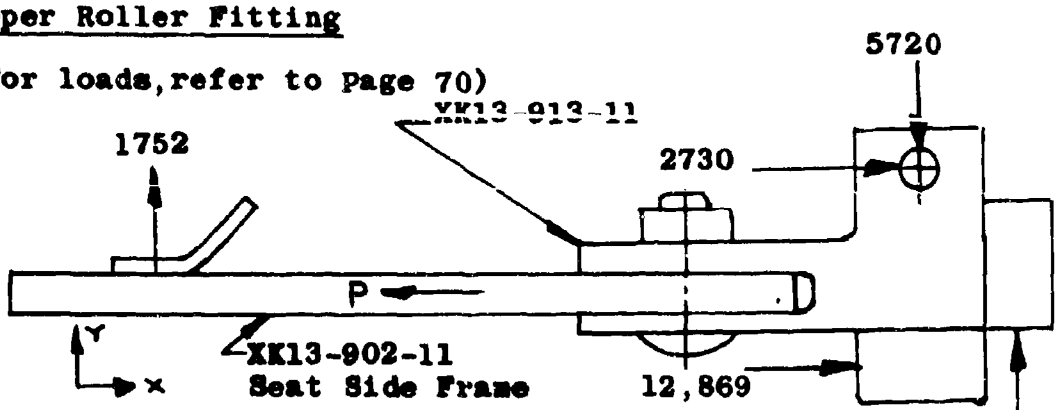
$$F_{su} = 95,000 \text{ p.s.i.}$$

$$M.S. = -.035$$

Clamp-up of the roller stud will relieve the conservative socket load, and fitting is expected to sustain the applied loads.

Upper Roller Fitting

(For loads, refer to Page 70)



$$\Sigma F_x = 0$$

$$12,869 + 2730 - P = 0$$

$$P = 15,604$$

Figure 27. Upper Roller Fitting Loading.

The moment at the main bolt due to the offset roller load is transferred by bearing of the bolt in the seat side, clamp-up of the main bolt, and by secondary bending of the fitting lugs.

Say that the moment transferred in the joint is 2000 inch-pounds. Balance the seat side frame:

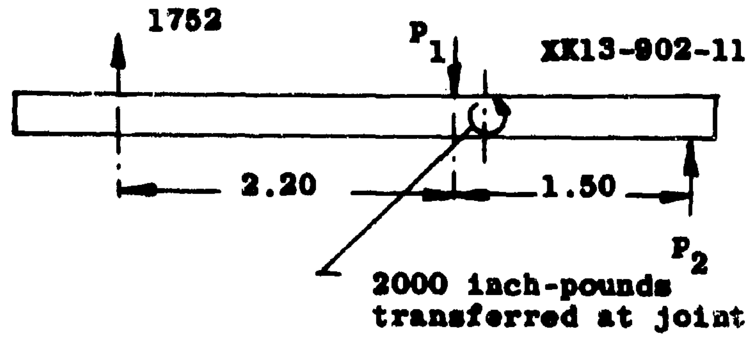


Figure 28. Seat Side Frame Loading at Upper Roller.

$$M_{P1} = 1752(2.20) - 1.50\,P_2 - 2000$$

$$M_{P1} = 3860 - 1.50\,P_2 - 2000$$

$$P_2 = 1240 \text{ pounds}$$

$$M_{P_2} = 1752(3.70) - 1.50\ P_1 - 2000$$

$$P_1 = 3000 \text{ pounds}$$

Secondary bending in lugs:

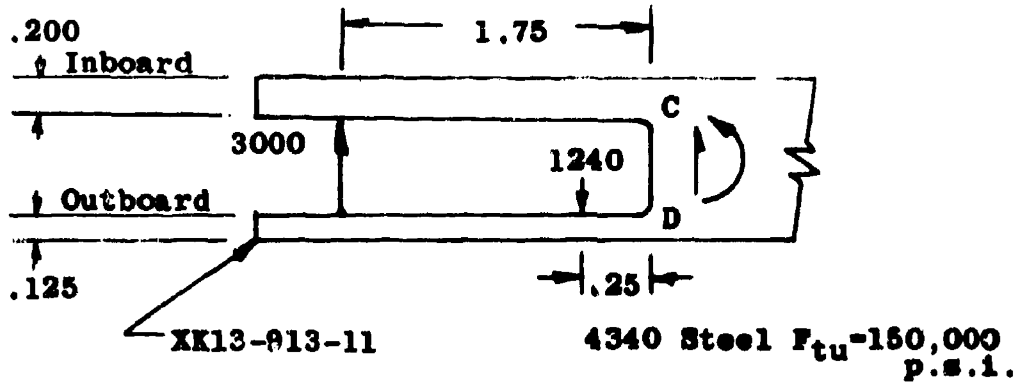


Figure 29. Upper Roller Fitting Lug Loading.

Say that 3000-pound shear is divided between lugs by stiffness ratio

$$\text{at C} \quad t = .200$$

$$t^3 = .008$$

$$\text{at D} \quad t = .125$$

$$t^3 = .00195$$

$$\text{Shear at C} = \frac{.008}{.008 + .00195}(3000)$$

$$\text{Shear at C} = 2420$$

Neglecting fixity; Moment at C $= 1.75(2420)$

$$M = 4230 \text{ inch-pounds}$$

$$f_b = \frac{6\ (4230)}{3.3(.20)^2}$$

$$f_b = 192{,}000 \text{ p.s.i.}$$

$$F_{tu} = 150{,}000 \text{ p.s.i.}$$
(Reference 1)

$$F_b = 1.25(150{,}000)$$
(Reference 1)

$$F_b = 187{,}500 \text{ p.s.i.}$$

$$R_b = 1.023$$

Load in inboard lug due to primary bending and direct tension:

$$P = \frac{15{,}604}{2} - 3700$$

$$P = 7802 - 3700$$

$$P = 4102 \text{ pounds tension}$$

Tension stress in lug:

$$f_t = \frac{4102}{.66}$$

$$f_t = 6240 \text{ p.s.i.}$$

$$R_t = \frac{6240}{150{,}000}$$

$$R_t = .0415$$

$$R_b + R_t = 1.064$$

Beam shear in lug:

$$f_s = \frac{2420}{3.3(.20)}$$

$$f_s = 3660 \text{ p.s.i.}$$

$$F_{su} = 95,000 \text{ p.s.i. (Reference 1)}$$

$$R_s = .0385$$

$$M.S. = \frac{1}{\sqrt{1.064^2 + .039^2}} - 1$$

$$M.S. \doteq -.06$$

This margin is considered adequate because the major load (bending) is based on conservative moment distribution.

Using the same methods as above, the margin of safety at point D was calculated to be a noncritical +0.50.

Seat Side Frame

This frame was checked for the load condition $P_x : P_z$ (reference Table 6). Loading was established by the following factors:

1. Weights are taken from Table 3, Page 37.

2. Load factors, which agree with the applied loads of Table 6, are 45g in x direction and 21.5g in z direction.

3. The lateral position of the center of gravity of the seat, with occupant, was conservatively assumed to be 3 inches from the centerline of the seat. To match this assumption, 70 percent of the occupant's loads were applied to the critical frame.

4. Loads in the x direction due to the occupant were proportioned in general agreement with the chest belt and shoulder harness loads (reference Page 50) and with seat belt and inverted vee belt loads (reference Page 52). Small arbitrary adjustments were made to distribute the loads in accordance withtthe estimated center of gravity of the occupant.

5. The load in the z direction due to the occupant was applied as a concentrated load.

6. The shoulder shield loads and the torso shield loads were applied by transferring the loads to support points on the frame.

7. The loads in x direction due to the seat components and seat back were considered to be uniformly distributed along the height of the seat.

8. The vertical load on the convex back panel of the seat causes a moment about the y axis. This moment is transferred to the seat frame by the frame-to-back connecting angles. For simplicity, this moment is shown as a couple with concentrated loads.

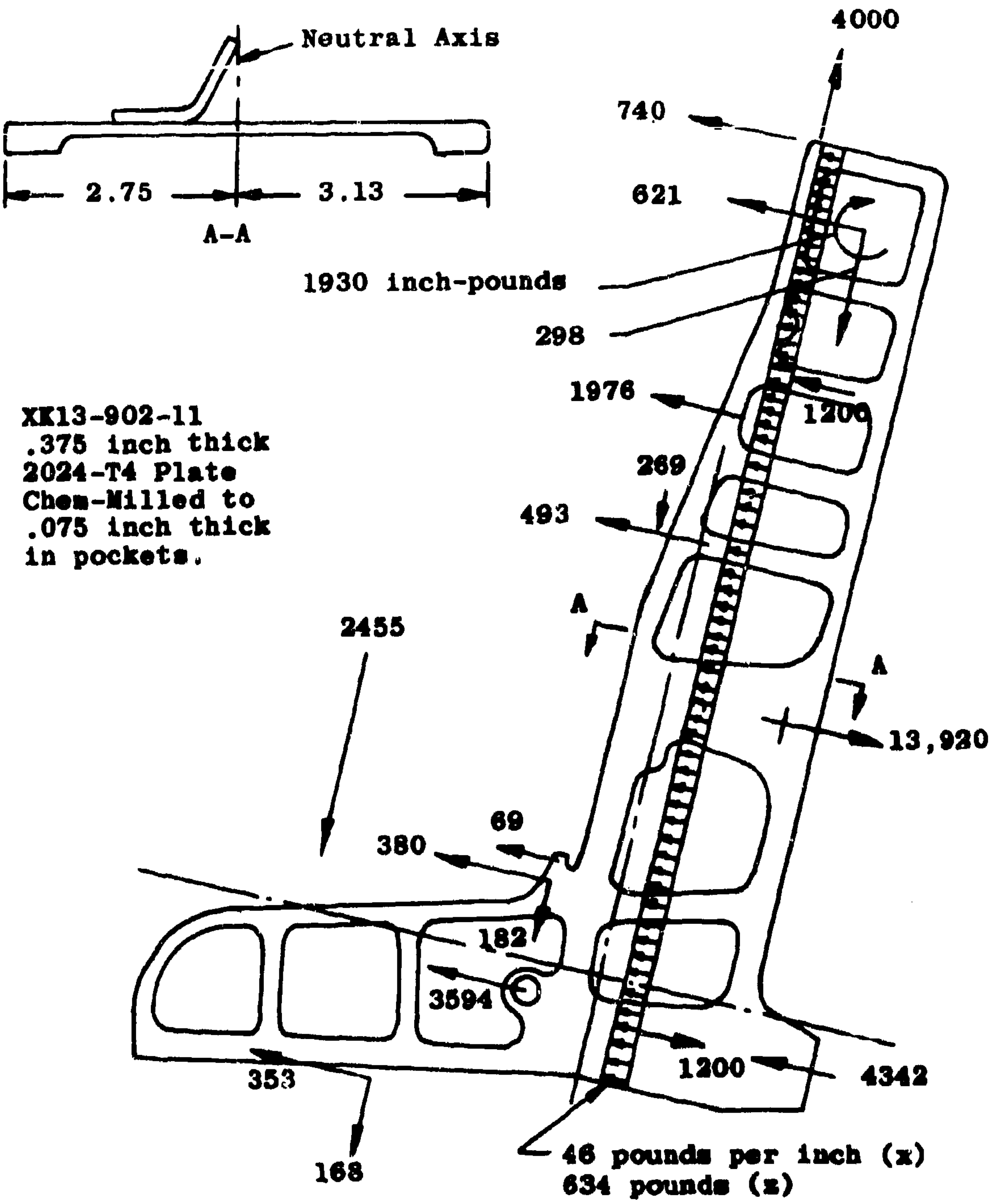
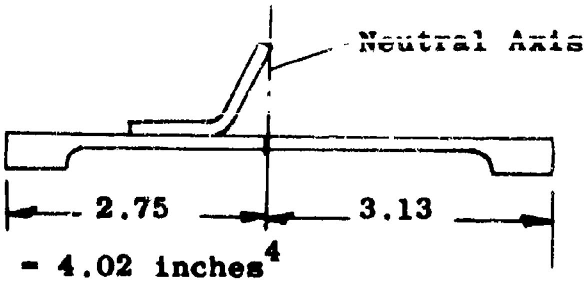


Figure 30. Seat Side Frame Loading.

Side Frame Bending at A-A



$$I = 4.02 \text{ inches}^4$$

$$\text{Area} = 1.17 \text{ square inches}$$

$$M_{A-A} = -740(15.5) + 4000\left(\frac{15.5}{29}\right)(1)$$

$$-621(13.25) + 298(1.9) - 1976(7.0)$$

$$- 493(3) - 269(3) - 46(155)\left(\frac{15.5}{2}\right)$$

$$+ 1930 - 1200(8.5)$$

$$M = -11{,}470 + 2140 - 8240 + 566 - 13{,}830$$

$$- 1475 - 808 - 5530 + 1930 - 10{,}200$$

$$M = 46{,}917 \text{ inch-pounds}$$

$$f_b = \frac{Mc}{I}$$

$$f_b = \frac{46{,}917(2.75)}{4.02}$$

$$f_b = 32{,}000 \text{ p.s.i. (Compression)}$$

$$f_b = 36{,}400 \text{ p.s.i. (Tension)}$$

Axial Load at A-A:

$$\text{Axial load} = + 4000 - 298 - 269 - 634\left(\frac{15.5}{29}\right)$$

Axial load = 3089 pounds (Tension)

$$f_t = \frac{P}{A}$$

$$f_t = \frac{3089}{1.17}$$

$$f_t = 2730 \text{ p.s.i.}$$

Combining Bending and Axial Stresses:

$$f_c = 32{,}000 - 2730$$

$$f_c = 29{,}270 \text{ p.s.i.}$$

$$f_t = 36{,}400 + 2730$$

$$f_t = 39{,}130 \text{ p.s.i.}$$

$F_{tu} =$ 64,000 p.s.i. (Reference 1)

$$R_t = .612$$

Shear at A-A:

$$V = 740 + 1200 + 621 + 1976 + 493$$

$$V = 5030 \text{ pounds}$$

$$f_s = \frac{5030}{6(.075)}$$

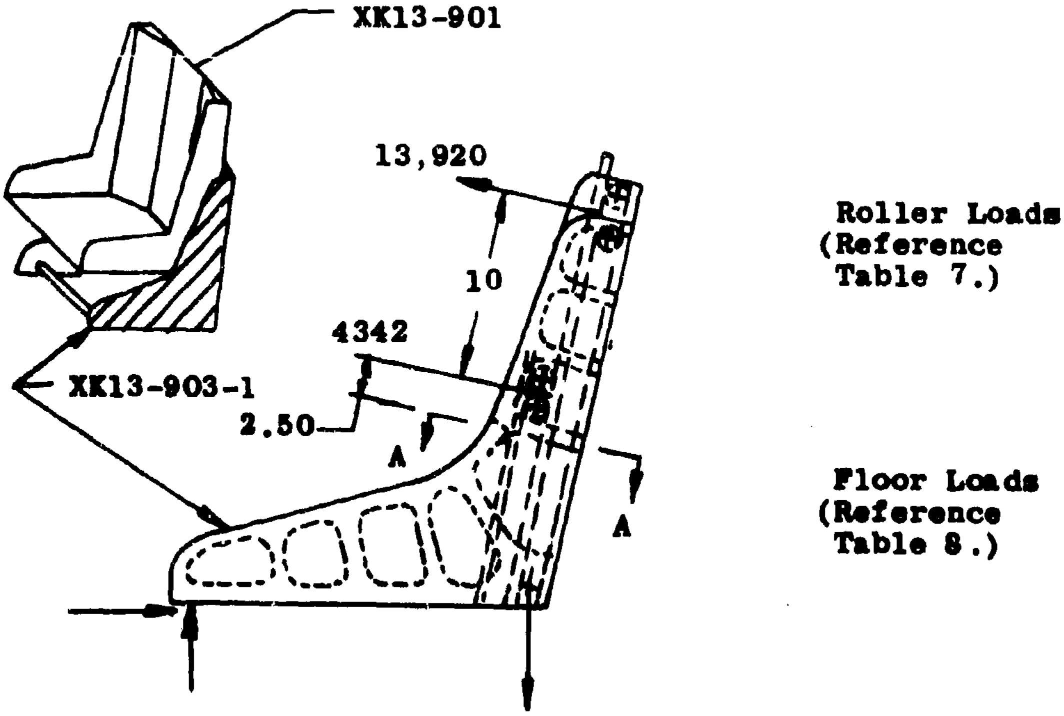
$$f_s = 12{,}900 \text{ p.s.i.}$$

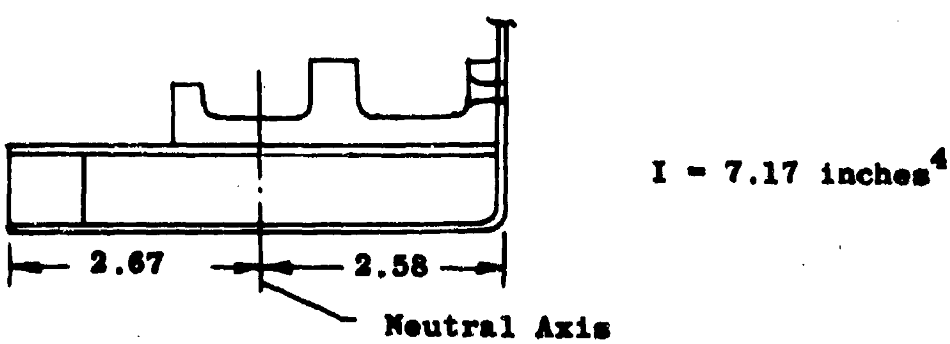
$F_{su} =$ 27,000 p.s.i. (Reference 13, Page 410)

$$R_s = .478$$

$$M.S. = \frac{1}{\sqrt{.612^2 + .478^2}} - 1$$

$$M.S. = .28$$





Material: 7075-T6 Bar and 7075-T6 Alclad Webs

A-A

Figure 31. Seat Support Side Beam Loading.

The critical section for bending and shear is Section A-A where the track web has been cut back and the beam depth is still relatively short.

Two conditions are checked: one with the seat in the uppermost position and the second with the seat 2.5 inches below the uppermost position. The first condition results in maximum moment and reduced shear on the critical section. The second condition applies maximum shear and reduced bending moment to the critical section:

For Uppermost Position:

$$M = -12.5(13,920) + 2.5(4342)$$

$$M = 174,200 + 10,820$$

$$M = -163,380$$

$$f_b = \frac{Mc}{I}$$

$$f_b = \frac{163,390(2.67)}{7.17}$$

$$f_b = 62,600 \text{ p.s.i.}$$

$$F_{tu} = 77,000 \text{ p.s.i.} \qquad \text{(Reference 1)}$$

$$R_b = .814$$

Shear and Torsion:

Conservatively neglecting shear reduction due to beam cap taper:

$$V = 13920 - 4342$$

$$V = 9578 \text{ pounds}$$

For shear and torsion, the side frame section is idealized as a constant section box.

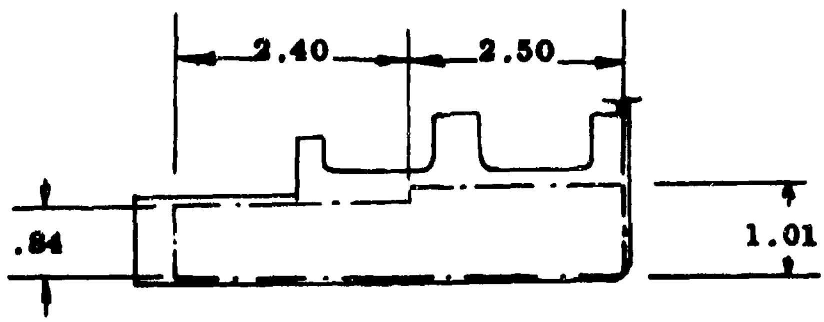


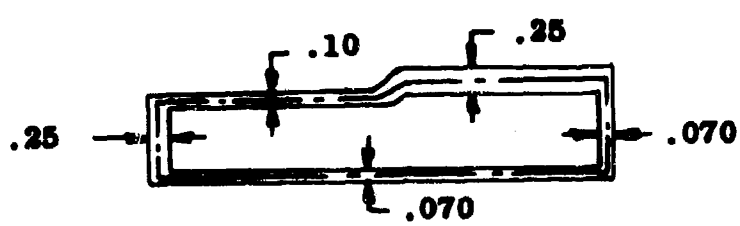
Figure 32. Side Beam Torque Box.

Area of box:

$$A = 2.40(.84) + 2.50(1.01)$$

$$A = 4.55 \text{ square inches}$$

Average wall thickness:



$$\bar{t} = \frac{2.40x.10+2.50x.25+1.01x.07+4.9x.07+.84x.25}{2.4 + 2.5 + 1.01 + 4.9 + .84}$$

$$\bar{t} = \frac{1.483}{11.65}$$

$\bar{t} = .127$

$A = 1.48$ square inches

Direct Shear:

$$f_s = \frac{9578}{1.48}$$

$f_s = 6460$ p.s.i.

Torsion:

$$f_s = \frac{T}{2At}$$

$$f_s = \frac{9578(1.00)}{2(4.55).127}$$

$f_s = 8290$ p.s.i.

The critical web is inboard and the shear stresses combine:

$f_s = 6460 + 8290$

$f_s = 14,750$ p.s.i.

$F_s = 33,000$ p.s.i. (Reference 13, Page 410)

$R_s = .447$

Combining Stress Ratios:

$$M.S. = \frac{1}{\sqrt{.814^2 + .447^2}} - 1$$

$M.S. = .075$

With the seat 2.5 inches below the uppermost position:

Bending Stress:

$$M = 13{,}920(10)$$

$$M = 13{,}920 \text{ inch-pounds}$$

$$f_b = \frac{Mc}{I}$$

$$f_b = \frac{13{,}920(2.67)}{7.17}$$

$$f_b = 51{,}900 \text{ p.s.i.}$$

$$R_b = \frac{51{,}900}{77{,}000} \qquad \text{(Reference 1)}$$

$$R_b = .675$$

Shear Stress (direct):

$$V = 13{,}920 \text{ pounds}$$

$$f_s = \frac{13{,}920}{1.48}$$

$$f_s = 9420 \text{ p.s.i.}$$

Shear Stress (torsion):

$$f_s = \frac{T}{2At}$$

$$f_s = \frac{13{,}920(1.0)}{2(4.55)(.127)}$$

$$f_s = 12{,}060 \text{ p.s.i.}$$

F_s = 33,000 p.s.i. (Reference 13, Page 410)

$$R_s = \frac{21,480}{33,000}$$

$$R_s = .652$$

$$M.S. = \frac{1}{\sqrt{.675^2 + .652^2}} - 1$$

$$M.S. = .065$$